August 30, 2023 09:00 PM GMT

Asia Primer | Asia Pacific

New Opportunities Unfolding for Smartphone Display

Foldable smartphone shipments could grow at a three-year CAGR of 45% over 2022-25, we estimate. Smartphone brands and those in the display supply chain will benefit the most from this trend.

Foldable display – the next big thing: Foldable display could be the next big spec upgrade in smartphones, in our view. We undertake a detailed analysis on the value proposition of foldable display, the state of current technology for key components, cost structure, growth potential and major beneficiaries in the relevant supply chain.

Foldable smartphone shipments to reach 45% CAGR in 2022-25: Smartphone display plateaued in 2018, in our view, with only modest migration and spec upgrades since. We think foldable displays, mostly in either book form or clamshell form (40-45%/55-60% split in 2022), could be the next major advancement in the smartphone space, since they can offer a more immersive viewing experience for entertainment, better multi-tasking setup for productivity, and a more compact form for portability. With continuous improvements in hardware performance and software optimization, we expect foldable smartphone shipments to reach 49.5mn units in 2025, implying 7% penetration by OLED smartphone display. Given its larger size and higher ASP, we estimate foldable displays will account for 9% and 16% of OLED smartphone displays on an area and revenue basis by 2025.

Display supply chain players to be key beneficiaries of the foldable theme: We expect display to be the component that sees the most meaningful dollar content growth in the foldable smartphone space, taking up 29% of the BOM cost for a typical book-type foldable smartphone. Flexible OLED is the only enabler of foldable smartphones at this stage and Samsung (005930.KS) is the biggest supplier with an 83% share of the foldable display market in 2022, followed by BOE (000725.SZ) at 15%. We expect Samsung to maintain its dominant position, though other vendors could catch up gradually with the technology advancements and capacity additions. Besides OLED, we see micro LED display playing a role when the technology matures. Longer term, we think other form factors like multiple-fold displays, rollable displays and stretchable displays could also be commercialized. In the display supply chain, players in the cover lens, OLED materials, and driver IC space could benefit from the increasing penetration of foldable smartphones.

More smartphone brands getting active on foldables: Samsung is the pioneer of the foldable smartphone, with 79% display market share as of 2022. However, Chinese smartphone brands are joining the game, launching their own foldable smartphone models, including Xiaomi (1810.HK), Huawei, Honor, Oppo, and Vivo. We believe foldables will help these players differentiate themselves and burnish their brand image.

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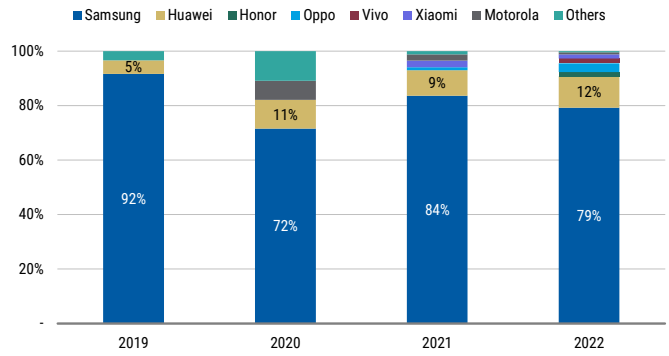
Key Charts

Exhibit 1: Different Form Factors for Foldable Smartphones

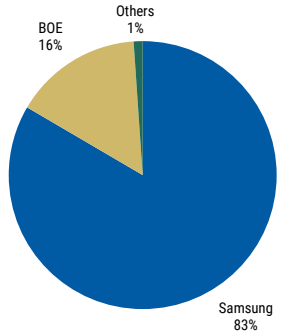
Source: GSMarena, Morgan Stanley Research

Exhibit 2: Global Foldable Smartphone Market Share



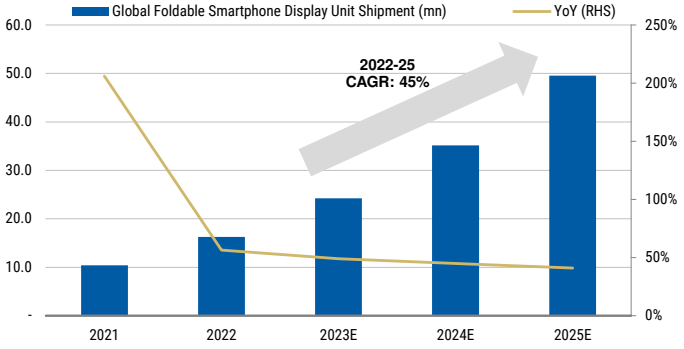
Source: IDC, Morgan Stanley Research

Exhibit 3: Global Foldable Smartphone Display Market Share (2022)



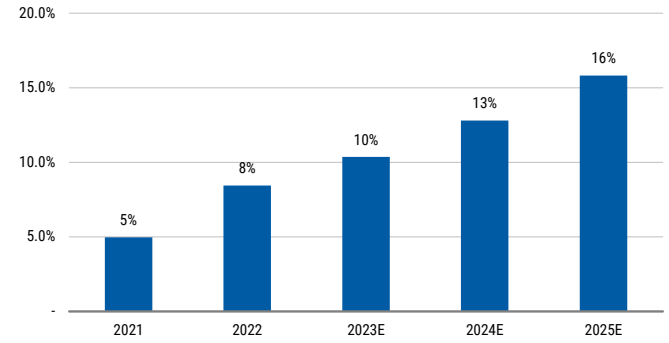
Source: Omdia, Morgan Stanley Research

Exhibit 4: 45% CAGR in Foldable Display Shipment



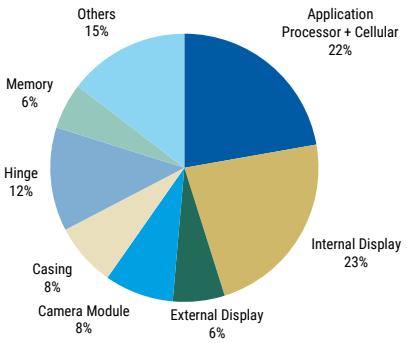
Source: Omdia, Morgan Stanley Research (E) estimates

Exhibit 5: Foldable Displays to Take 16% of OLED Smartphone Display Revenue in 2025



Source: Omdia, Morgan Stanley Research (E) estimates

Exhibit 6: BOM Cost Breakdown for Typical Book-type Foldable Smartphone



Source: Morgan Stanley Research estimates. BOM = bill of materials

Key Beneficiaries

Exhibit 7: Key Beneficiaries of the Foldable Display Theme

Component	Suppliers	Ticker	MS Coverage	Note
Display				
OLED/Micro LED	Samsung	005930.KS	Shawn Kim	83% market share in foldable display (2022)
	LG Display	034220.KS	Shawn Kim	Tier-one OLED supplier now, potential supplier of foldables
	BOE	000725.SZ	Derrick Yang	16% market share in foldable display (2022)
	TCL	000100.SZ	Derrick Yang	1% market share in foldable display (2022)
	Tianma	000050.SZ	Derrick Yang	Tier-two OLED supplier now, potential supplier of foldables
	Visionox	002387.SZ	Derrick Yang	Tier-two OLED supplier now, potential supplier of foldables
OLED Materials	Duk San Neolux	213420.KQ	Ryan Kim	Major light emitting materials for OLED
Driver IC	Novatek	3034.TW	Daniel Yen	Major OLED dirver IC supplier
	Chipbond	6147.TWO	Dylan Liu	Major OLED driver IC backend supplier
	UMC	2303.TW	Charlie Chan	Major driver IC foundry
Micro LED	AUO	2409.TW	Derrick Yang	Backplane and assembly for micor LED
	Innolux	3481.TW	Derrick Yang	Backplane and assembly for micor LED
	Ennostar	3714.TW	Derrick Yang	LED chip supplier for micro LED
	Sanan	600703.SS	Derrick Yang	LED chip supplier for micro LED
	HC Semitek	300323.SZ	Not Covered	LED chip supplier for micro LED
	Playnitride	6854.TW	Not Covered	LED chip and mass transfer for micro LED
	K&S	KLIC.O	Not Covered	Mass tranfer equipment for micro LED
Hinge				
Hinge	KH Vatec	060720.KQ	Not Covered	Major hinge supplier for Samsung
	Fositek	6805.TWO	Not Covered	Major hinger supplier for Chinese smartphone brands
	Jarllytec	3548.TWO	Not Covered	Major hinger supplier for Chinese smartphone brands
Cover Lens				
UTG	Corning	GLW.N	Meta Marshall	Raw ultra thin glass supplier
	Schott	NA	NA	Raw ultra thin glass supplier
	NEG	5214.T	Not Covered	Raw ultra thin glass supplier
	AGC	5201.T	Not Covered	Raw ultra thin glass supplier
	Dowoo Insys	NA	NA	UTG finisher
	eCONY	NA	NA	UTG finisher
	Lens Tech	300433.SZ	Derrick Yang	UTG finisher
	Biel	NA	NA	UTG finisher
	Token	300088.SZ	Derrick Yang	UTG finisher
CPI	Kolon	120110.KS	Not Covered	Colorless Polyimide supplier
	Sumitomo Chem	4005.T	Takato Watabe	Colorless Polyimide supplier
	LG Chem	051910.KS	Young Suk Shin	Colorless Polyimide supplier
Brand				
	Samsung	005930.KS	Shawn Kim	79% market share (2022); Galaxy Z Fold 5/Galaxy Z Flip 5
	Xiaomi	1810.HK	Andy Meng	1% market share (2022); Mix Fold 3
	Apple	AAPL.O	Erik Woodring	No foldables so far, but could potentially join the game
	Huawei	NA	NA	12% market share (2022); Mate X3
	Honor	NA	NA	2% market share (2022); Magic V2
	Oppo	NA	NA	3% market share (2022); Find N2/ Find N2 Flip
	Vivo	NA	NA	2% market share (2022); X Fold2/X Flip
	Motorola	NA	NA	1% market share (2022); Razr 40 Ultra

Source: Company data, Omdia, IDC, Morgan Stanley Research

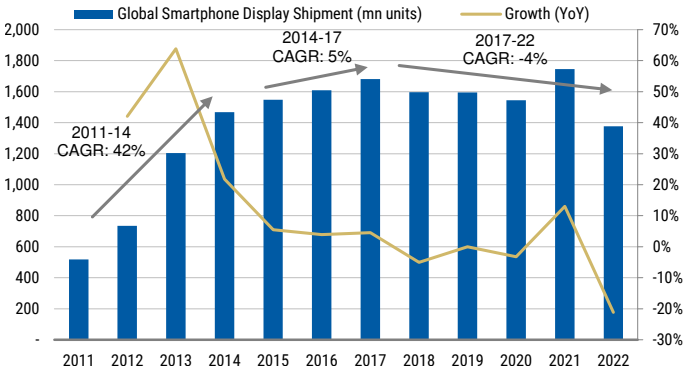
Executive Summary

Smartphone Display Shifting from Volume Growth to Spec Upgrade

The smartphone display market has gone through three distinct stages in the past decade, with the focus gradually shifting from volume (amid increasing penetration) to area shipped (prompted by size migration) to display technology upgrade.

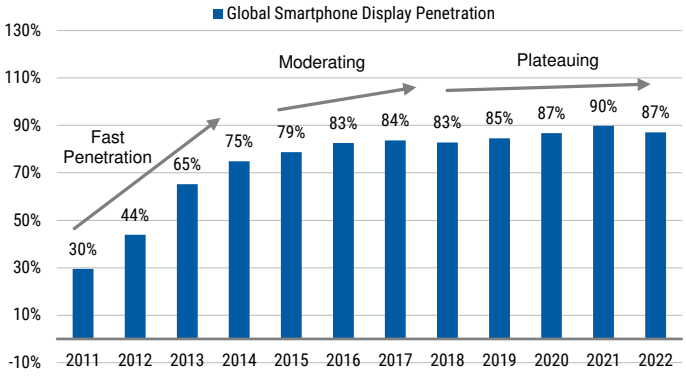
- **Before 2014: Fast growth on increasing penetration**
  - Unit shipment CAGR at 42% vs. overall mobile phone display shipment of 4% CAGR (penetration rising quickly from 30% in 2011 to 75% in 2014)
  - Average area per display grew at an 18% CAGR (average size up from 3.6" to 4.7")
  - Revenue CAGR at 33%
- **2015-17: Moderating growth**
  - Unit shipment CAGR at 5% vs. overall mobile phone display shipment at 1% CAGR (penetration up from 75% in 2014 to 83% in 2017)
  - Average area per display expanded at a 7% CAGR (from 4.7" in 2014 to 5.3" in 2017)
  - Revenue CAGR at 16%
- **2018 and beyond: Plateauing**
  - Unit shipment -4% vs. overall mobile phone display shipment at -5% CAGR
  - Average area per display increasing at a 6% CAGR (from 5.3" in 2017 to 6.5" in 2022)
  - Revenue CAGR -1%

Exhibit 8: Global Smartphone Display Shipment



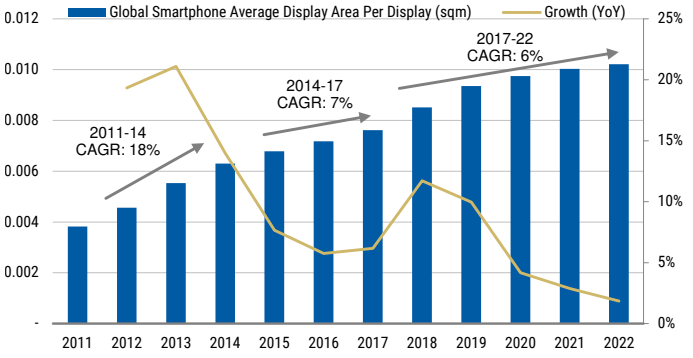
Source: Omdia, Morgan Stanley Research

Exhibit 9: Global Smartphone Display Penetration



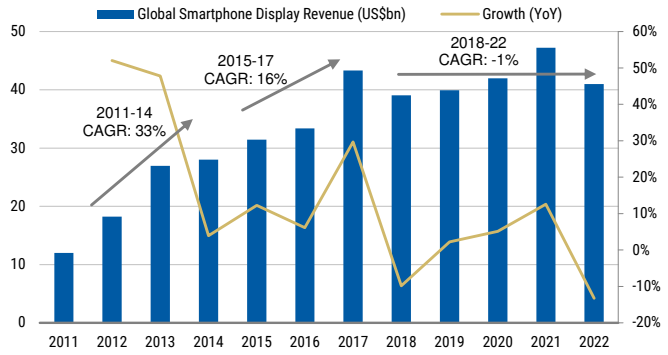
Source: Omdia, Morgan Stanley Research

Exhibit 10: Global Smartphone Average Area per Display



Source: Omdia, Morgan Stanley Research

Exhibit 11: Global Smartphone Display Revenue



Source: Omdia, Morgan Stanley Research

What Can Foldable Displays Offer?

Current foldable smartphone models come in either the book-type or clamshell-type form. In general, we would say the two key advantages of the foldable smartphones are their bigger screen size and better portability.

From a supply chain perspective, book-type foldable smartphones can rejuvenate the size migration of smartphone displays, which are now capped at around 6"-7", as the new structure can bring the display size above the 7" threshold without compromising on the pocketability of the device. While the size migration might not look significant at one inch (i.e., from 6"-7" to 7"-8"), the incremental area is quite meaningful, given that the aspect ratio will be much wider in the unfolded state. Taking the Samsung Galaxy Z Fold 4 as an example, the 7.6" unfolded main display can offer 118% more display area compared to its 6.2"external display.

Book-type foldable smartphones

This design remains at the regular size of 6" when folded, but can spread to 7"-8" when unfolded. This could basically transform the smartphone into a small-sized tablet and offer a better user experiences in many use cases.

- **Browsing internet or using apps:** With the bigger display, more information can be shown and seen at once, without the need to frequently scroll up and down or sometimes left and right to read all the content.
- **Watching videos or playing games:** When it comes to these use cases for entertainment, a bigger display definitely works better as it can provide a more immersive experience.
- **Multi-tasking:** The bigger display can also enable more possibilities in multi-tasking, as the screen can be split into multiple views to show different information simultaneously. For example, the user can have the email inbox on the left hand side, while reading or composing an email on the right hand side. The user can also run multiple apps at the same time, which could be convenient when interacting with friends through different platforms or potentially use the drag-and-drop function for file and picture transfers.

Clamshell-type foldable smartphones

This design has the display at the common 6"-7" size when unfolded, but can become much more compact at around 3" when folded. While this form factor does not expand the screen to a larger size, it can offer better portability by making the device easier to carry.

Another minor merit of this design, though less relevant to the display, is that the device can stand on its own without any external support when partially folded, which could come in handy when used for video calls or taking pictures without help from others. This comes with the book-type foldable form factor as well.

Exhibit 12: Different Form Factors for Foldable Smartphones

Book-type Foldable Smartphone

Clamshell-type Foldable Smartphone

Source: GSMArena, Morgan Stanley Research

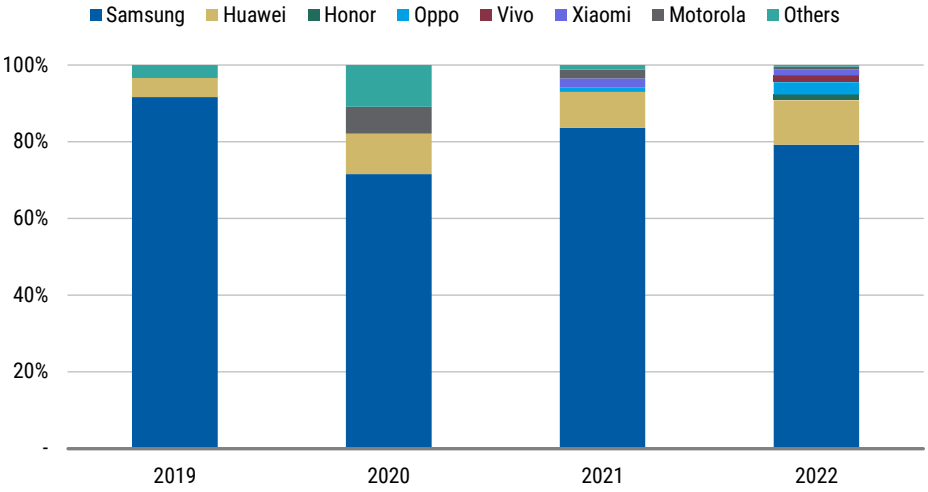
Samsung Dominates the Market, but More Brands Are Joining the Game

The launch of Samsung Galaxy Z Fold in February 2019 ushered in a new era in smartphone history, as it commercialized the foldable form factor for the first time. Not long after that, Samsung further broadened its offerings by unveiling the Samsung Galaxy Z Flip in February 2020, which introduced the clamshell design to the mobile phone device again, but this time in smartphones vs. previously in feature phones.

After Samsung's groundbreaking initiatives, other smartphone brands gradually followed suit and launched their own foldable smartphone models. As of now, major smartphone brands like Huawei, Honot, Oppo, Vivo, and Xiaomi all have foldable models in the market.

As the first brand to offer foldable smartphones, Samsung remains the market leader. In 2022, it held a 79% share of the global market on a unit basis, followed by Huawei at 12%, Oppo at 3%, Vivo at 2%, Honor at 2%, Xiaomi at 1% and Motorola at 1%. With more players allocating more resources to the foldable smartphone market, Samsung's market share might gradually normalize in the coming years albeit it will likely continue to grow its shipment.

Exhibit 13: Global Foldable Smartphone Market Share Trend



Source: IDC, Morgan Stanley Research

OLED and Micro LED Both Feasible Technologies

OLED the current enabler of foldable smartphones

Given that the OLED display is self emissive without the backlight module and can be based on flexible substrates, it is pretty much the only feasible technology for the foldable display currently. Globally, the majority of flexible OLED materials are owned by Korean and Chinese panel makers.

Samsung is the most aggressive promoter of the OLED display and was the early adopter of this technology since the inaugural edition of the famous Galaxy S series in 2010. As a result, Samsung has dominated OLED supply in the past decade and owns 39% of the global flexible OLED capacity in 2022, according to our estimates.

LG Display has also been an early mover in the flexible OLED space, but due to its financial constraints, its capacity share was not that meaningful at 11% in 2022.

BOE was a late comer and started to ramp up its flexible OLED capacity from 2018, but it has been expanding quickly since then and should be ramping up its third Gen 6 flexible OLED fab this year. On our estimates, BOE owned 25% of the global capacity in 2022.

Other tier-two players in China, including TCL, Tianma and Visionox, also aspire to gain more traction in the flexible OLED market, with the 2022 capacity share reaching 4%, 9%, and 12%, respectively.

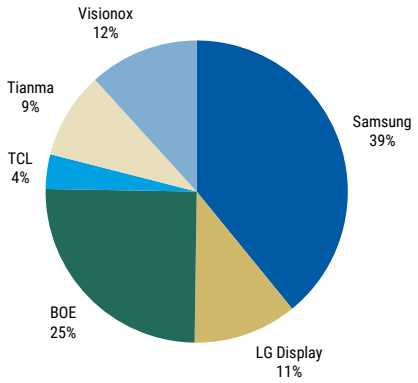
Samsung Dominating the Foldable Display Supply

Due to the limitations of the technology capabilities and differences in strategic focus, the foldable smartphone display supplier base is much more concentrated than capacity would suggest. Samsung dominated the market and represented 83% of shipments in 2022, which is understandable given its position in the foldable smartphone end market and its internal sourcing strategy. Other than Samsung, BOE took the majority of the remaining shipment with a 16% share last year and other suppliers were insignificant.

Despite the current status, we believe that the supplier base will become more diversified

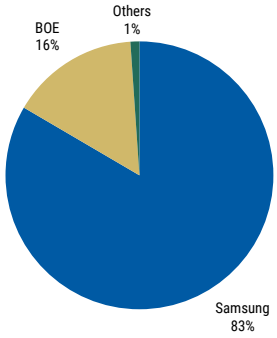
with the increasing penetration of foldable smartphones and a bigger addressable market for panel makers in the coming years.

Exhibit 14: Global Flexible OLED Capacity Market Share (2022)



Source: Omdia, Witsview, Morgan Stanley Research

Exhibit 15: Global Foldable Smartphone Display Market Share (2022)

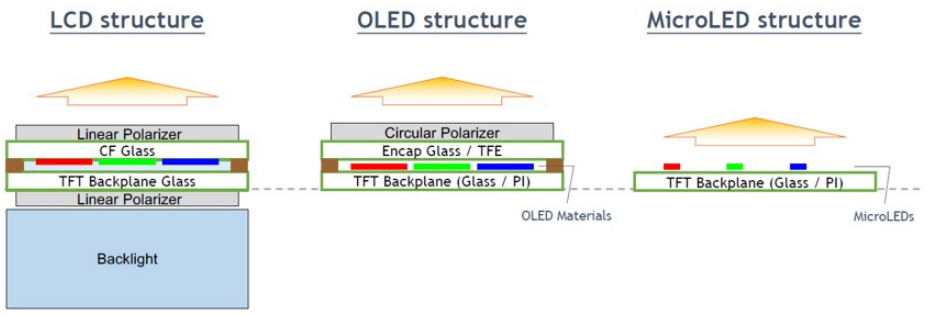


Source: Omdia, Morgan Stanley Research

Micro LED a Potential Candidate in the Longer Term

Micro LEDs refer to chips with a dimension smaller than 0.075mm, which are used to construct self-emissive displays, instead of acting as the light source for a backlight module. The technical structure for micro LED displays is different from that of traditional LCD displays. Without the need for a backlight module and most optical films, the structure of the micro LED is simpler than the LCD display. Furthermore, the micro LED display also has a slimmer structure than its self-emissive OLED counterpart, as the former is built upon more durable inorganic materials. We believe that the simpler structure and better durability of micro LEDs could make them an ideal candidate for foldable devices compared to OLED.

Exhibit 16: Technical Structure of Different Display Technologies



Source: Playnitride, Morgan Stanley Research

Micro LED is often dubbed the "ultimate" display technology by industry players, as it seems to possess many advantages compared to mainstream technologies. Here, we focus on the comparison of micro LED and OLED, two feasible technologies for foldable displays.

- **Better flexibility:** Though OLEDs can offer good flexibility as it is based on the polyimide substrate, the simpler structure for micro LEDs can enable better durability when it comes to foldablility, since it can prevent the risk of delamination.

- **Better luminance and power efficiency:** Though both are self-emissive displays, micro LED chips have better efficiency in converting electricity into light than the light emitting layers within OLEDs, so the former needs less power to deliver the same luminance as the latter.
- **Better durability and longer lifespan:** The micro LED display is based on inorganic materials and is thus less susceptible to moisture and oxygen, which could accelerate decay in the OLED display. Thus, the micro LED display can achieve a longer lifespan and be more durable in harsher operating environments.
- **Better transparency:** As the micro LED display has a smaller light emitting area vs. OLED, it could achieve a higher level of transparency, at >60%, vs. 30-50%, on average, for OLED.
- **Wide operating temperature:** The micro LED display can function normally at temperatures between minus 100 degrees celsius to positive 120 degrees celsius, vs. OLED's range of minus 30 degrees celsius to positive 70 degrees celsius.

Despite the benefits that micro LED can bring to the display market, currently we see only a few high-end products featuring the technology and full-scale commercialization looks years away, since the supply chain would need to improve the production yield of LED chips, increase throughput in the mass transfer of LED chips onto driving backplanes, as well as make inspections and repairs more efficient, before we could see more devices adopting micro LED displays and the supply becomes confident enough to bring this into foldable devices.

Dynamics in Other Key Components

Cover Lens - UTG dominates

Colorless polyimide (CPI) is one of the materials that can be used as the cover lens for foldable smartphone, since it is flexible and has good optical properties. However, it is soft by nature and more susceptible to scratches, so the layers need to be made thicker and there is usually an additional hard coating layer required to improve its surface flatness, texture feel and scratch resistance.

Ultra thin glass (UTG) is another feasible material for the cover lens. The inherent properties of UTG are quite different from CPI. UTG has good scratch resistance, but poor shock resistance, so an additional layer of PET is often added as a shock absorber. Meanwhile, it can offer a more solid feel on a more even surface, but that comes at the expense of a bigger bending radius.

Currently, UTG has a bigger share in the global foldable smartphone market on a unit basis, given that Samsung adopts this solution; Huawei and Honor still prefer CPI for their foldable devices.

Exhibit 17: UTG Supply Chain Players

UTG Raw Glass	UTG Finisher
Schott (Advanced)	Dowoo insys
Corning (Advanced)	eCONY
NEG	Lens Tech, Biel, Token, Kaimao, etc.
AGC	
Schott (Regular)	
Corning (Regular)	

Source: Omdia, Morgan Stanley Research

Exhibit 18: CPI Supply Chain Players

CPI Suppliers	Hard Coating Suppliers
Kolon	DNP, MSK
Sumitomo Chem	Songwoo
SKC	SKC
SK Innovation	SK Innovation, HughStar
LG Chem	LG Chem

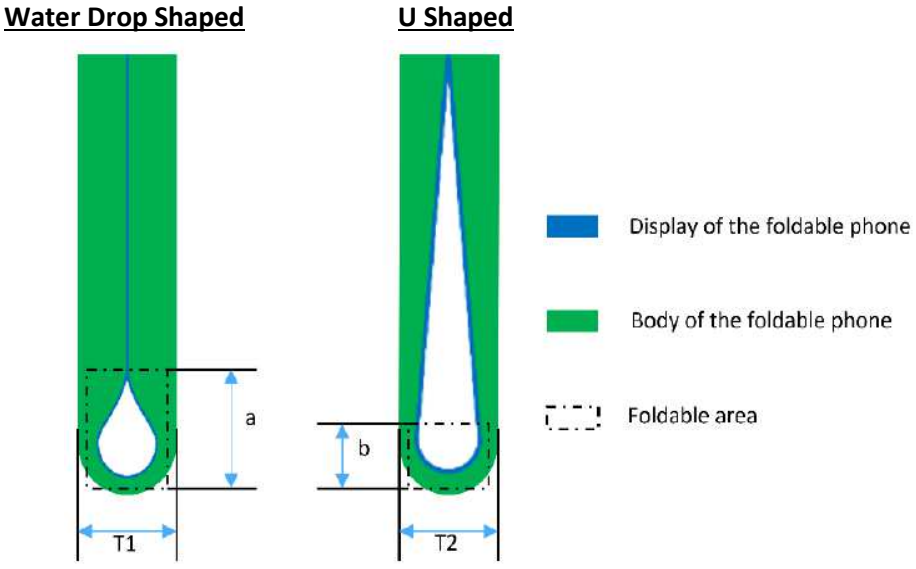
Source: Omdia, Morgan Stanley Research

Hinge - Water drop-shaped design gaining in popularity

Compared to the more traditional U-shaped hinge design, the water drop-shaped hinge offers a less visible gap between the sides when the device is fully folded, which means a slimmer form factor and sleeker appearance, in our opinion. However, this likely comes at a price, as the display needs to have higher curvature in the water drop-shaped design, which might compromise the durability and reliability of the display to some extent over time, given that the display needs to withstand relatively more tension and compression.

Our checks indicate that Samsung has moved to the water drop shape design in its newly released models, vs. previously using the U shape design.

Exhibit 19: Different Hinge Designs for Foldable Smartphones



Source: Omdia, Morgan Stanley Research

Software - Optimization critical to user experiences

Despite the significant hardware spec upgrade, especially on the display side, we believe that most of the software will need to be tailored to make use of the incremental display

area to its fullness. On this front, we think there are a few areas worth highlighting:

- **Screen continuity:** Images or apps need to flow seamlessly between the external and internal display
- **Multiple windows:** The multiple-window setup is the basis for multi-tasking and a better user experience will depend on the interactability between the windows, such as the drag and drop function
- **Aspect ratio adjustment:** The aspect ratio of the image or apps need adjust quickly to fit the internal and external displays. Furthermore, the aspect might need to adjust flexibly under the multiple-window setup

This could be a chicken-and-egg situation, especially for app developers, since the bigger the installed base for foldable smartphones, the more economic sense it makes for the developer to optimize the app for the unique use case scenarios. We thus expect this to continue evolving for a better user experience in the future.

Displays Taking 29% of BOM for Foldable Smartphone

For a mainstream book-type foldable smartphone model, we estimate the display accounts for 29% of the total bill of materials (BOM) cost, with 23% for the internal foldable display and another 6% for the external regular display. The application processor adopted by the foldable should be the most high end one, given the premium positioning of the device, so we estimate that the application processor will account for 22% of the BOM cost. Another key component is the mechanical parts, especially the casing and hinge, which we think could account for 20% of the BOM cost.

45% CAGR for Foldable Smartphone Displays in 2022-25e

7% of smartphone OLED unit shipment in 2025

According to the data from Omdia, the total shipment of foldable displays was 16.3mn units in 2022, or 2.8% of global OLED shipments. With more smartphone brands launching foldable smartphone models and the ecosystem becoming more mature, we expect shipment of foldable smartphones to increase at a 45% CAGR in the coming three years to reach 49.5mn units by 2025. This would represent 6.8% of total OLED smartphone shipments.

9% of smartphone OLED area in 2025

As the book-type foldable display is much larger than the mainstream smartphone display and it takes a roughly 40% share of the total foldable market, it's conceivable that foldable display represented a bigger portion of the smartphone OLED display shipment on an area basis than on a unit basis.

Per Omdia data, foldable displays shipment area reached 220,000 square meters in 2022, accounting for 3.7% of the total OLED display area in 2022. We estimate that it could grow at a three-year CAGR of 46% to 690,000 square meters in 2025, or 8.8% of the global OLED display area.

16% of smartphone OLED revenue in 2025

In 2022, foldable smartphone displays generated US$2.9bn of revenue globally, representing 8.4% of the total OLED smartphone display revenue of US$32.9bn. Under the assumption of 12% ASP decline per year, we estimate that total foldable smartphone display revenue could hit US$5.8bn in 2025, which implies a three-year CAGR of 28% and would contribute 15.8% to total OLED smartphone display revenue.

More Possibilities Ahead

Though the current foldable smartphones still have room for optimization, the supply chain is already exploring more possible design concepts that could draw more attention and make the smartphone even more versatile in use cases. Below we list a few of these new architectures in the order of technology readiness.

Multiple-fold displays

The multiple-fold display allows the smartphone to spread out into an even larger display, e.g. 8.x" or 12.x", than the current book-type foldable display. There are three configurations to embody this, including:

- **G-type folding:** both sides of the display can be folded either inward or outward to form the G shape from the top view
- **S-type folding:** one side of the display is folded inward and the other folded outward, forming the S shape from the top view

Exhibit 20: Different Types of Multiple-fold Displays

G Type Folding **S Type Folding**

Source: Omdia, Morgan Stanley Research

The multiple-fold structure to some extent magnifies the benefits of the current foldable one, as it allows an even bigger display area when the screen is fully unfolded. Nonetheless, this comes with incremental challenges, such as the additional folding area where malfunctions tend to occur, the manufacturing yield and cost of the larger-size flexible OLED display, the choice of cover lens materials in the S type design given the different bending radius in the in-folding and out-folding structures, etc.

Rollable display

Besides folding the displays to change the sizes in different use cases, a similar purpose can be achieved by wrapping and expanding a certain part of the display. In Exhibit 66, we show two simple diagrams for the devices with a rollable display.

Though both foldable and rollable displays are based on flelxible displays, they could have different advantages and challenges, since they are configured in different mechanical structures. Compared to foldable displays, rollable displays can accommodate a larger

bending radius, have a lower risk of delamination and have no crease. However, some components are needed incrementally, e.g., the motor and sliding mechanism, which could take up more space, create another source of durability issues and make the device more difficult to achieve the same level of water resistance.

Stretchable displays

The stretchable display is probably the most remote one among the transformable display structures, since the current OLED display does not seem that suitable to enable this design, given its limited stretchability. Our checks indicates that the current flexible OLED display can be stretched by only 5-10%, while the next generation of display technology, micro LED, could theoretically be stretched by 30-40%.

There have been some panel makers showcasing samples of the stretchable displays, including AUO and LGD based on the micro LED structure. Although the stretchable displays can be useful in many applications, such as portable devices, wearable devices, and automobiles, the micro LED display itself seems to have a lot room for improvement, as we discussed in the previous session, so we believe it will take much more effort and resources devoted to this space, before we can see the stretchable display gaining more traction in the real world.

Key Beneficiaries from the Foldable Display Theme

Samsung Electronics (005930.KS, Shawn Kim): Samsung's dominance of the small size OLED market with over 83% revenue share is likely to sustain due to a combination of its early investment in the technology, ability to mass produce high-quality displays, strategic internal drive to differentiate foldable phones and its reputation for producing high-end displays for consumer electronics. We estimate its OLED revenue will grow 10% YoY in 2024 and see larger long-term upside from its foldable laptop panels and products expected in 2025-26.

LG Display (034220.KS, Shawn Kim): LGD is well positioned to capture foldable notebook PCs to be presented in 2025 and launched in 2026, in our view. The company offers unique product portfolios with technology advantages such as 17-inch foldable OLED for PC and 8-inch 360-degree foldable OLED that fits different customized needs. We believe LGD's potential for share gains and expanding TAM via automotive and PC OLED penetration in the medium to long term is underappreciated.

BOE (000725.SZ, Derrick Yang): BOE is the second largest foldable display supplier with a 16% share in 2022. While it is a latecomer, its positioning as a independent display supplier could be increasingly attractive to customers along with its gradually narrowing gap in technology capability compared to the leading supplier, since there will be no concern on potential conflict of interest. We thus believe BOE should be able to repeat its growth trajectory in the OLED smartphone display market and become an important second source for most of the major brand customers. Longer term, BOE is also developing its technology in the micro LED space to broaden its offerings.

Corning (GLW.N, Meta Marshall): Corning participates in the smartphone market via its Gorilla Glass product line (reported within the Specialty Materials segment), which accounted for ~9%/~US$1.3bn of total revenue in 2022A. Corning should see modest

benefit from increased content per device (with displays expected to account for 29% of the foldable device BOM), and is well positioned with current market leader Samsung (which will use Gorilla Glass in upcoming flagship Galaxy devices, and uses Gorilla Glass on both its Fold and Flip models). That said, we see limited scope for foldable device demand to translate to positive estimate revisions until adoption becomes more meaningful as Display and Optical account for 60%+ of consolidated EPS

Novatek (3034.TW, Daniel Yen): As one of leading high-end OLED DDIC suppliers, we expect the pickup of foldable smartphone will increase the TAM and benefit Novatek in the long run. However, the magnitude of the revenue contribution to the GC DDIC supply chain will be highly dependent on the progress of Chinese panel makers. We are also concerned on the OLED competition from Chinese OLED DDI designers and pricing pressure on mid to low end LCD DDI.

Apple (AAPL.O, Erik Woodring): We believe Apple will launch a foldable device in the next few years, with our latest supply chain checks indicating a potential foldable iPhone launch in Fall 2026. There's also the potential that Apple releases a foldable MacBook in the next few years, as well. Given the still relative infancy of foldables in smartphones, as well as the premium price point of foldable devices, we don't believe Apple is at risk of losing market share to foldables in the near-term, but we do believe an entrance into foldables could be a catalyst for accelerating iPhone upgrades/new user acquisition and contracting replacement cycles. That said, the average iPhone OLED display costs US$70-90 per unit vs. current smartphone foldable displays at US$150-170, and therefore we believe Apple will be forced to raise iPhone prices by at least US$225 per unit when including foldable technologies to maintain its premium gross margin profile.

Xiaomi (1810.HK, Andy Meng): Xiaomi's third foldable smartphone model, Mix Fold 3, adopts the Pol-less Plus technology for tis inner display, which could reduce the energy consumption by 52% to materially extend the battery life and improve the user experience. While the foldable smartphone only accounts for very small portion of Xiaomi's total smartphone shipment, it is an important pillar of Xiaomi's premium smartphone strategy. It could also help Xiaomi establish a high-end brand image considering the higher ASP of foldable smartphones.

See today's report, Greater China Technology Hardware: Key Beneficiaries of the Foldable Display Theme for more details.

Smartphone Display Shifting from Volume Growth to Spec Upgrade

The smartphone display market has gone through three distinct stages in the past decade or so, with the focus gradually shifting from volume (as penetration increased) to area shipment (prompted by screen sizes increasing) and eventually to display technology upgrade.

Before 2014: Fast Growth on Increasing Penetration

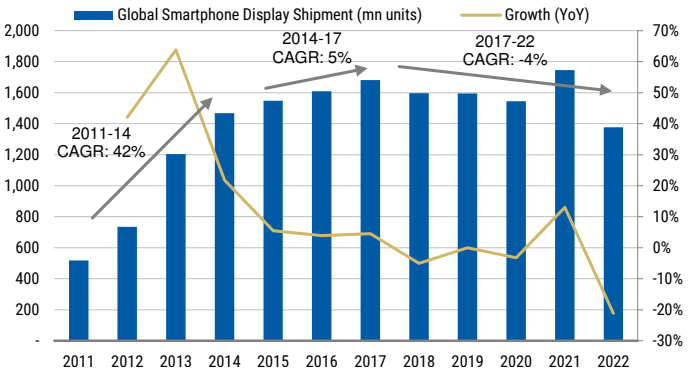
While smartphones started to gain more attention from the mid 2000s, Apple's launch of the first iPhone model in January 2007 was undoubtedly a watershed moment in the history of smartphone. After that, the smartphone began to penetrate into existing mobile phones, which were later called feature phones to differentiate from smartphones, and thus the smartphone display shipment witnessed a period of strong growth before 2014.

While our data does not stretch back to 2007, it does show a shipment CAGR of 42% in 2011-2014 for smartphone display vs. a mere 4% CAGR for overall mobile phone display shipment over the same period of time. The penetration of smartphones into the mobile phone market rose quickly from 30% in 2011 to 75% by 2014.

Meanwhile, the size migration was another factor driving smartphone display growth, as the average area per display increased at a CAGR of 18% in 2011-2014, driving the average size from 3.6" in 2011 to 4.7" in 2014.

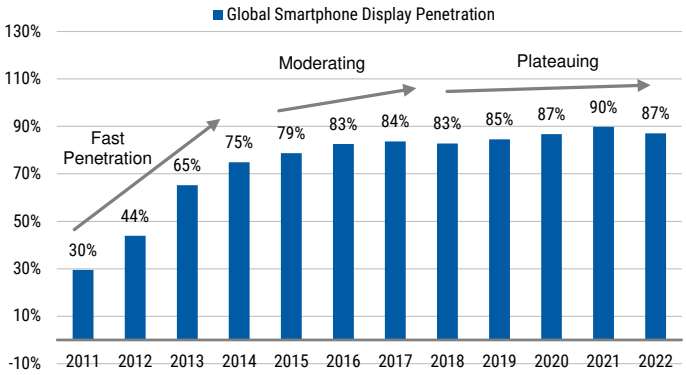
All these factors combined led to a 33% CAGR for smartphone display revenues over 2011-2014.

Exhibit 21: Global Smartphone Display Shipment



Source: Omdia, Morgan Stanley Research

Exhibit 22: Global Smartphone Display Penetration



Source: Omdia, Morgan Stanley Research

2015-2017: Moderating Growth

From 2015, smartphone display continued to benefit from volume growth, though the pace started to moderate, since the penetration of smartphone display into the overall mobile market was approaching a relatively high level, so incremental additions became smaller.

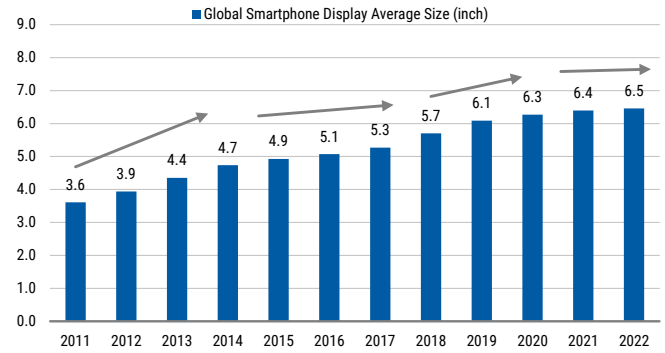
Smartphone display shipment increased at a CAGR of 5% over 2014-2017. While this was still better than the overall mobile phone display shipment CAGR of 1%, it represented a meaningful slowdown compared to the 42% CAGR seen in 2011-2014. Smartphone penetration kept moving higher, but at a more moderate pace to reach 83% by 2017.

Size migration also shifted at a steady pace during this time. The average area per display grew at a CAGR of 7% during 2014-17, with the average expanding from 4.7" in 2014 to 5.3" in 2017.

One trend worth mentioning is that OLED display penetration saw a meaningful pickup to 24% in 2016 vs. ~18% in 2011-15, which was reflective of the shift towards OLED displays among the flagship models from Android brands, such as Huawei.

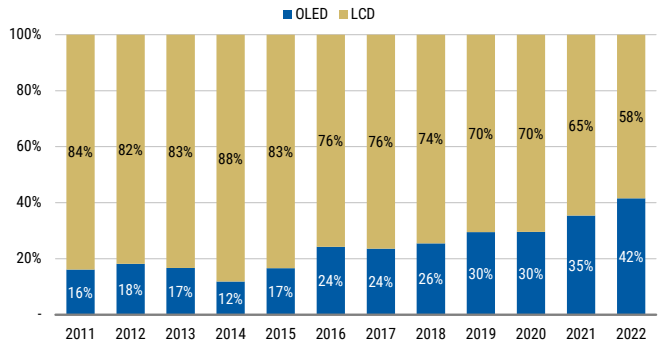
As a result of the slower growth both in unit shipment and size migration, revenue CAGR decelerated to 16% during this period of time.

Exhibit 23: Global Smartphone Display, Average Size



Source: Omdia, Morgan Stanley Research

Exhibit 24: Global Smartphone Display, Tech Breakdown



Source: Omdia, Morgan Stanley Research

2018 and Beyond: Plateauing

After 2018, smartphone display growth has been largely aligned with total mobile phone shipment, as the penetration rate was approaching a plateau at over mid-80%. Thus, the smartphone display shipment CAGR of -4% in 2017-22 was similar to the CAGR of -5% for the overall mobile phone display shipment.

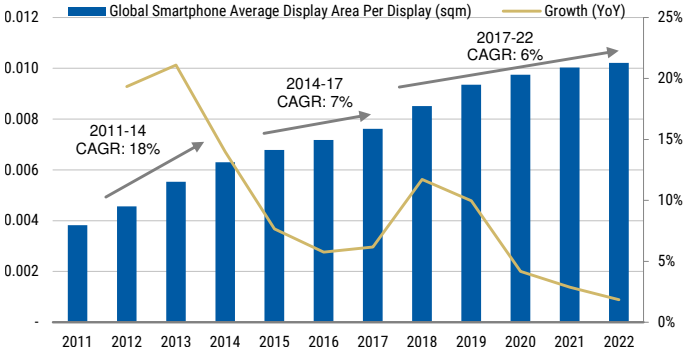
One our estimates, the size migration sustained during 2017-22, with the average area per display increasing at a 6% CAGR, will lead to the average size of smartphones reaching 6.5" in 2025 vs. 5.3" in 2017. We believe that this is prompted by the adoption of over 6" displays by flagship models from leading smartphone brands.

For example, Samsung Galaxy S8/S8+ moved to a 5.8"/6.2" display in 1Q17 vs. the Galaxy S7/7 Edge at 5.1"/5.5", Samsung Galaxy Note 8 migrated to a 6.3" display from Galaxy Note 7 at 5.7". Meanwhile, Apple iPhone upgraded the display size to 5.8"/6.5"/6.1" for XS/XS Max/XR in 4Q18 from iPhone 8/8 Plus/X at 4.7"/5.5"/5.8" in 4Q17, dropping the 4.7" model from the line-up.

Another key theme during this period was that OLED display has been gaining traction among smartphone brands, extending its presence from flagship models into mid- to high-end models as well, which drove OLED penetration from ~25% in 2016-18 to 42% in 2022.

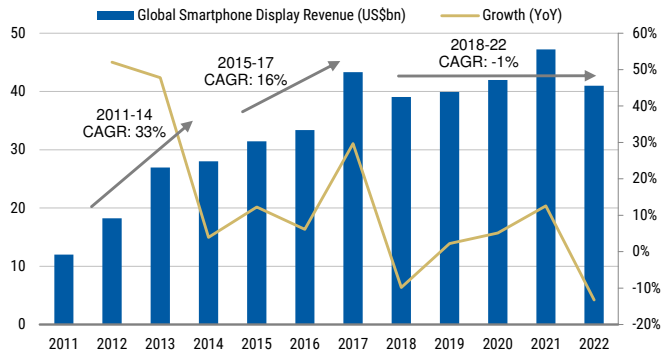
These dynamics added up to the revenue CAGR of -1% in 2017-2022.

Exhibit 25: Global Smartphone Average Areas per Display



Source: Omdia, Morgan Stanley Research

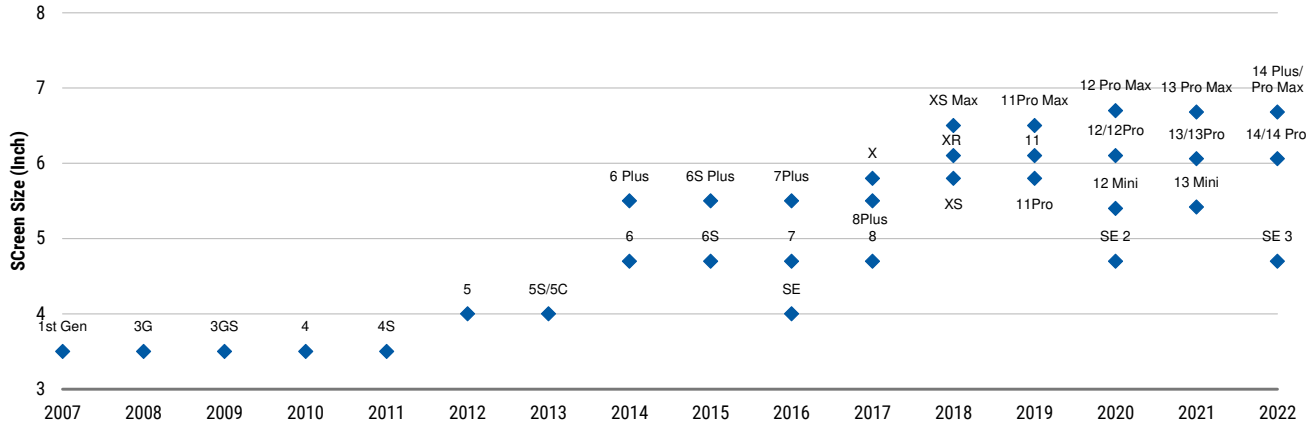
Exhibit 26: Global Smartphone Display Revenue



Source: Omdia, Morgan Stanley Research

Exhibit 27:

iPhone Display Size Evolution



Source:Morgan Stanley Research

Value Propositions of Foldable Smartphones

Book and Clamshell Are Becoming Major Form Factors

We see merit in foldable displays, in particular their larger display and better portability.

Exhibit 28: Different Form Factors for Foldable Smartphones

Book-type Foldable Smartphone

Clamshell-type Foldable Smartphone

Source: GSMArena, Morgan Stanley Research

In most cases, when a smartphone is folded, the user can take a glance at basic information, such as time, date, weather, and notifications, through either a separate external display (in-folding form factor) or part of the big display (out-folding form factor), so simple tasks can be done with the device in the compact form.

Moreover, for those adopting the in-folding form factor, which is the mainstream design now, the external casing can provide good protection for the internal main display to reduce the risk of scratches or cracks while the device is not in use.

Exhibit 29: External Display for Basic Information and Casing to Protect Internal Display

Source: GSMArena, Morgan Stanley Research

Book-type Foldable Smartphone

This book-type foldable smartphone is one within a group of foldable smartphone models that will maintain the regular size of 6" when folded, but can spread to 7"-8" when unfolded. This could effectively transform the smartphone into a small-sized tablet and

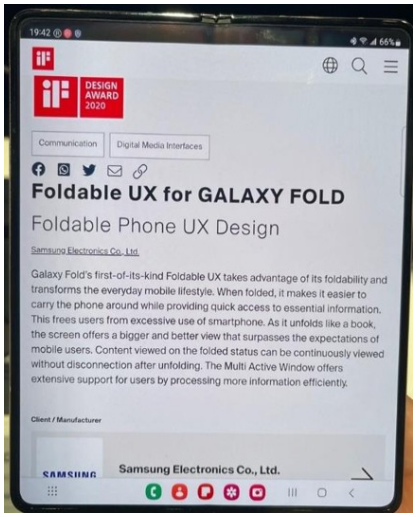
offer a better user experiences in many use cases.

Browsing internet or using apps

With the bigger display, more information can be shown and seen at once, without the need to frequently scroll up and down or sometimes left and right to read all content.

Exhibit 30: Better Viewing Experiences on Foldable Display

Foldable Smartphone Display



Regular Smartphone Display

Source: Morgan Stanley Research

Watching videos or playing games

When it comes to use cases for entertainment, a bigger display works well as it can provide a more immersive experience

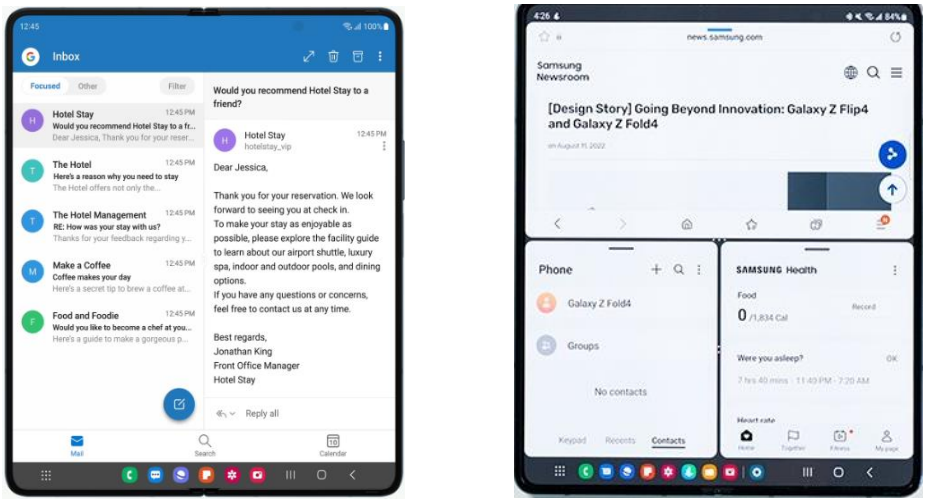
Exhibit 31: More Immersive Video or Gaming Experiences

Source: Samsung, Morgan Stanley Research

Multi-tasking

The bigger display can also enable more possibilities when multi-tasking, as the screen can be split into multiple sections to show different information simultaneously. For example, the user can have the email inbox on the left hand side, while reading or composing an email on the right hand side. The user can also run multiple apps at the same time, which could be convenient when interacting with friends through different platforms or potentially using the drag-and-drop function for file and picture transfers.

Exhibit 32: Multi-tasking on Foldable Smartphones



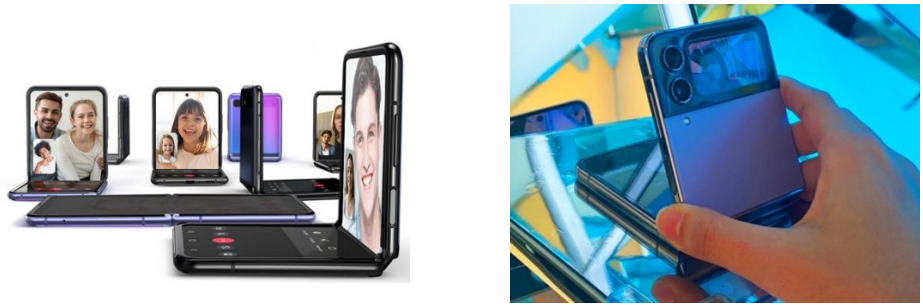
Source: Samsung, Morgan Stanley Research

Clamshell-type Foldable Smartphone

The clamshell foldable smartphone has a regular 6"-7" size display when unfolded, but can become much more compact at around 3" when folded. While this form factor does not expand the screen to a larger size, it can offer better portability by making the device easier to carry.

Another minor merit of this design, though less relevant to the display, is that the device can stand on its own without any external support when partially folded, which could come in handy when the user is having a video call or taking pictures without help from others. This comes with the book-type foldable form factor as well.

Exhibit 33: Use Cases for Foldable Smartphones

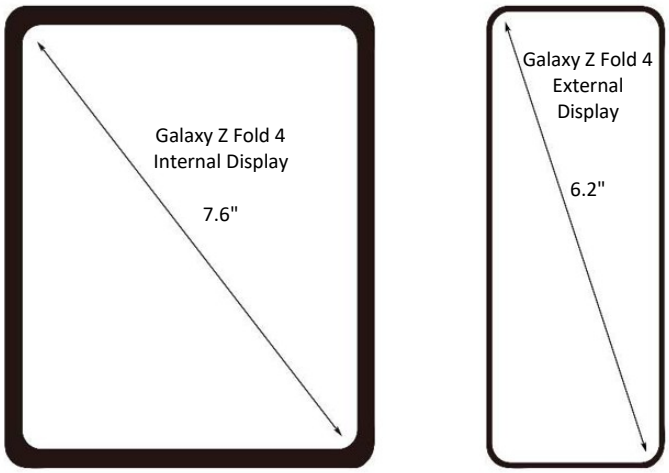


Source: Samsung, Morgan Stanley Research

Implications for smartphone display

While size migration might not seem significant at face value, the incremental area provided is quite meaningful, given that the aspect ratio is much wider when the phone is unfolded. Taking the Samsung Galaxy Z Fold 4 as an example, the 7.6" main display offers 118% more display area when unfolded compared to its 6.2" external display. In that sense, one foldable display is equivalent to more than two current mainstream smartphone displays on an area basis, so the proliferation of foldable smartphones could help drive smartphone demand.

Exhibit 34: Foldable Displays Offer Much More Display Area than Regular Displays



Source: Morgan Stanley Research

Samsung Dominating the Market, but More Brands Are Joining the Game

Galaxy Z Fold Marked the Beginning of the Foldable Era

The launch of Samsung Galaxy Z Fold in February 2019 ushered in a new era in smartphone history, as it commercialized the foldable form factor for the first time. Not long after that, Samsung further broadened its offerings by unveiling the Samsung Galaxy Z Flip in February 2020, which re-introduced the clamshell design to the mobile phone market, this time to smartphones not feature phones.

After Samsung's groundbreaking initiatives, other smartphone brands gradually started to follow the suit and launch their foldable smartphone models. To date, major smartphone brands like Huawei, Honot, Oppo, Vivo, and Xiaomi all have their own foldable models in the market.

Exhibit 35: Foldable Smartphone Models - Book Type

Brand	Samsung	Xiaomi	Huawei	Huawei	Honor	OPPO	Vivo	Google
Model	Galaxy Z Fold5	Mix Fold 3	Mate X3	Mate Xs 2	Honor Magic V2	Find N2	X Fold2	Pixel Fold
Product								
Launch Date	2023	2023	2023	2022	2023	2022	2023	2023
Folding Type	In-folding	In-folding	In-folding	Out-folding	In-folding	In-folding	In-folding	In-folding
External screen size (inch)	6.2	6.56	6.4	6.5	6.43	5.54	6.53	5.8
External screen resolution	2316*904	2520*1080	2504*1080	2480*1176	2376*1060	2120*1080	2520*1080	2092*1080
Internal screen size (folded one) (inch)	7.6	8.03	7.85	7.8	7.92	7.1	8.03	7.6
Internal screen (folded one) resolution	2176*1812	2160*1916	2496*2224	2480*2200	2344*2156	1920*1792	2160*1916	2208*1840
Refresh Rate (Hz)	120	120	120	120	120	120	120	120
Fold Type	Book	Book	Book	Book	Book	Book	Book	Book
Cover	NA	UTG	NA	CPI	NA	UTG	NA	NA
Weight (g)	253	255/259	239/241	255/257	231/237	233/237	279	283
Dimension when folded (mm)	154.9 x 67.1 x 13.4	161.2 x 73.5 x 10.96/10.86	156.9 x 72.4 x 11.8	156.5 x 75.5 x 11.1	156.7 x 74.1 x 9.9 or 10.1	132.2 x 72.6 x 14.6	161.3 x 73.4 x 12.9	139.7 x 79.5 x 12.1
Dimension when extended (mm)	154.9 x 129.9 x 6.1	161.2 x 143.3 x 5.3	156.9 x 141.5 x 5.3	156.5 x 139.3 x 5.4	156.7 x 145.4 x 4.7 or 4.8	132.2 x 140.5 x 7.4	161.3 x 143.4 x 6	158.7 x 139.7 x 5.8
Battery	4400mAh	4800mAh	4800mAh	4880mAh	5000mAh	4520mAh	4800mAh	4821mAh
AP/CPU	Snapdragon 8 Gen 2	Snapdragon 8 Gen 2	Snapdragon 8+ Gen 1	Snapdragon 888 4G	Snapdragon 8 Gen 2	Snapdragon 8+ Gen 1	Snapdragon 8 Gen 2	Google Tensor G2
DRAM (gb)	12	12	12	8	16	12	12	12
Storage (gb)	256	256	256	256	256	256	256	256
Launch Price (starting from) (US$)	1,799	1,250	2,352	2,699	1,250	1,180	1,300	1,799

Source: GSMarena, Morgan Stanley Research

Exhibit 36: Foldable Smartphone Models - Clamshell Type

Brand	Samsung	Huawei	OPPO	Vivo	Motorola/Lenovo	Motorola/Lenovo
Model	Galaxy Z Filp5	Pocket S	Find N2 Flip	X Flip	Razr 40 Ultra	Razr 2022
Product						
Launch Date	2023	2022	2022	2023	2023	2022
Folding Type	In-folding	In-folding	In-folding	In-folding	In-folding	In-folding
External screen size (inch)	3.4	1.04	3.26	3	3.6	2.7
External screen resolution	748*720	340*340	720*382	682*422	1066*1056	800*573
Internal screen size (folded one) (inch)	6.7	6.9	6.8	6.74	6.09	6.7
Internal screen (folded one) resolution	2640*1080	2790*1188	2520*1080	2520*1080	2640*1080	2400*1080
Refresh Rate (Hz)	120	120	120	120	165	144
Fold Type	Clamshell	Clamshell	Clamshell	Clamshell	Clamshell	Clamshell
Cover	NA	CPI	UTG	NA	NA	UTG
Weight (g)	187	190	191	198	184.5/188.5	200
Dimension when folded (mm)	85.1 x 71.9 x 15.1	87.3 x 75.5 x 15.2	85.5 x 75.2 x 16	86.4 x 75.3 x 16.6	88.4 x 74 x 15.1	86.5 x 79.8 x 17
Dimension when extended (mm)	165.1 x 71.9 x 6.9	170 x 75.5 x 7.2	166.2 x 75.2 x 7.5	166.4 x 75.3 x 7.8	170.8 x 74 x 7	167.0 x 79.8 x 7.6
Battery	3700mAh	4000mAh	4300mAh	4400mAh	3800mAh	3500mAh
AP/CPU	Snapdragon 8 Gen 2	Snapdragon 778G 4G	Mediatek Dimensity 9000+	Snapdragon 8+ Gen 1	Snapdragon 8+ Gen 1	Snapdragon 8+ Gen 1
DRAM (gb)	8	8	8	12	8	8
Storage (gb)	256	128	128	256	256	128
Launch Price (starting from) (US$)	999	818	895	870	999	890

Source: GSMarena, Morgan Stanley Research

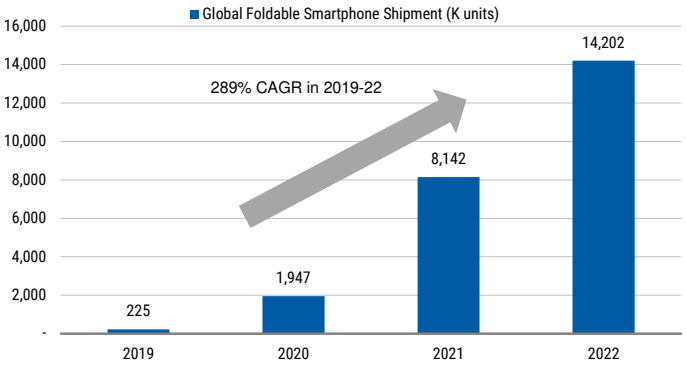
Foldable Still Niche, but Consumer Interest Is Growing

Foldable smartphone shipment grew at a CAGR of 298% in 2019-2022. While this growth looks pretty significant, part of it should be attributed to the low base. in 2022, there were 14.2mn units of foldable smartphone being shipped into the market, registering 74% YoY growth from 8.1mn units in 2021. However, on a total unit basis, this represents only 1.0% of global smartphones in 2022.

On a revenue basis, foldable smartphones grew at a 243% CAGR in 2019-2022 to reach US$18.0bn in 2022 vs. US$0.3bn in 2019. This accounted for 3.6% of the global smartphone market in 2022 vs. only 0.1% in 2019.

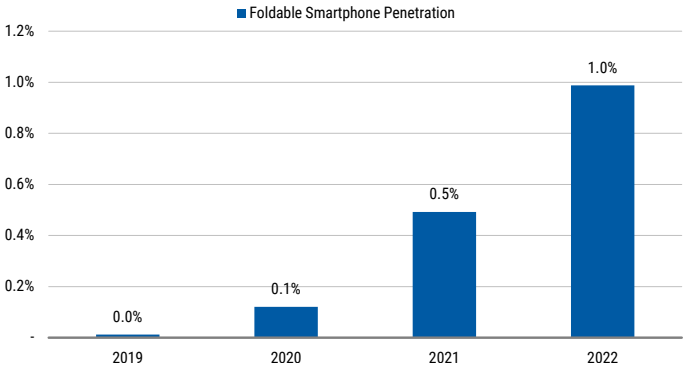
Though foldable smartphones are likely to account for only a minor share of the global smartphone market in the coming years, we believe that its importance will continue to grow, given that this could be one of the key form factors for differentiation.

Exhibit 37: Global Foldable Smartphone Shipment



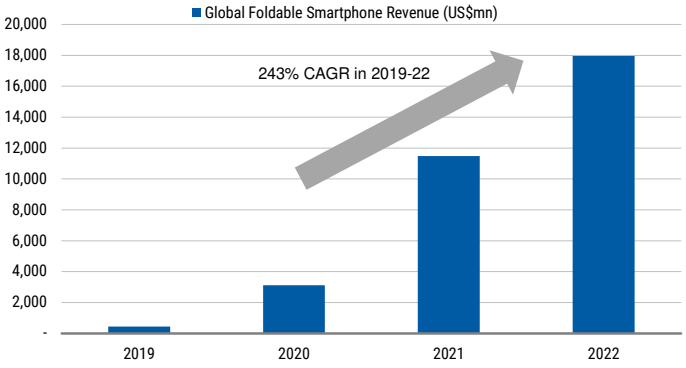
Source: IDC, Morgan Stanley Research

Exhibit 38: Global Foldable Smartphone Penetration - Unit Basis



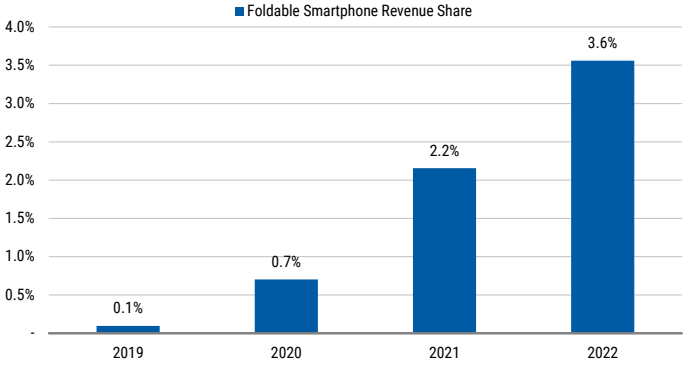
Source: IDC, Morgan Stanley Research

Exhibit 39: Global Foldable Smartphone Revenue



Source: IDC, Morgan Stanley Research

Exhibit 40: Global Foldable Smartphone Revenue Share

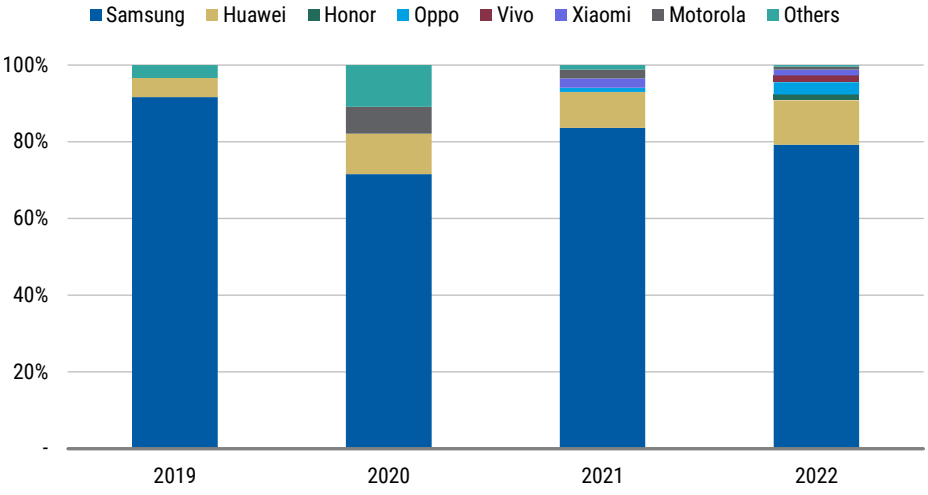


Source: IDC, Morgan Stanley Research

Samsung Leads the Pack on Market Share

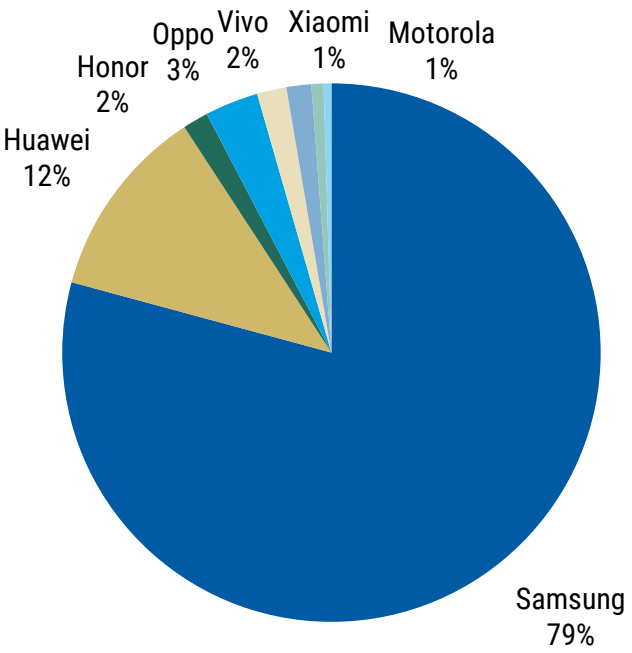
As the first brand to bring forth foldable smartphones, Samsung remains the major player in the market. In 2022, it held a 79% share in the global market on a unit basis, followed by Huawei at 12%, Oppo at 3%, Vivo at 2%, Honor at 2%, Xiaomi at 1% and motorola at 1%. However, with more players allocating more resources to the foldable smartphone market, Samsung's market share is likely to normalize in the coming years.

Exhibit 41: Global Foldable Smartphone Market Share Trend



Source: IDC, Morgan Stanley Research

Exhibit 42: Global Foldable Smartphone Market Share (2022)



Source: IDC, Morgan Stanley Research

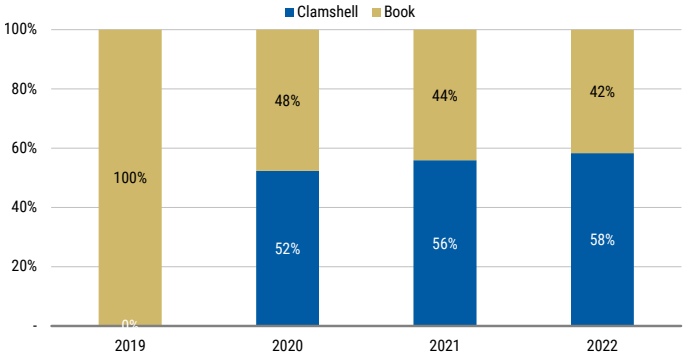
Clamshell Taking 50-60% of Shipment Share

Since the first clamshell foldable smartphone became available in February 2020, clamshell foldable smartphones have consistently taken a more than 50% share of the foldable smartphone market, registering 52%, 56% and 58% share in 2020, 2021 and 2022, respectively, on a unit basis.

On a revenue basis, clamshell foldable smartphones represented 43%, 40% and 46% of global foldable smartphone revenue in 2020, 2021 and 2022, respectively.

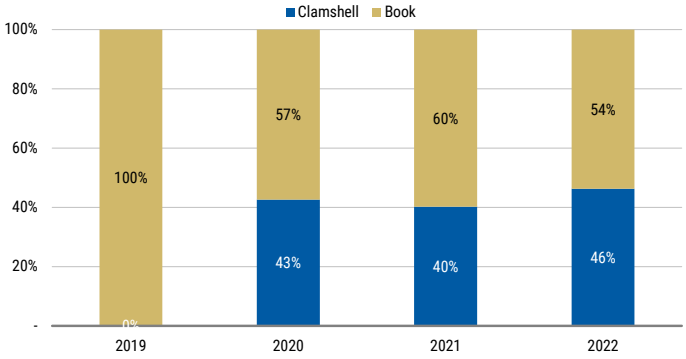
We think this is probably due to its relatively lower prices and more mature ecosystem, compared to its book-type counterparts.

Exhibit 43: Global Foldable Smartphone Form Factor Breakdown - Unit Basis



Source: IDC, Morgan Stanley Research

Exhibit 44: Global Foldable Smartphone Form Factor Breakdown - Revenue Basis



Source: IDC, Morgan Stanley Research

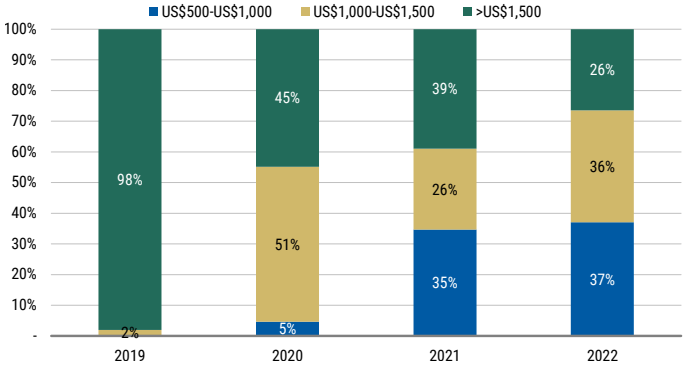
Premium Pricing for Foldable Smartphones

In 2022, 37% of foldable smartphones were priced at the range of US$500-US$1,000,

36% at the range of US$1,000-US$1,500 and 26% at US$1,500 or higher. In 2019-2022, the blended ASP declined at a CAGR of 14%, driven partially by the mix change and partially by the ASP reductions for some series as well.

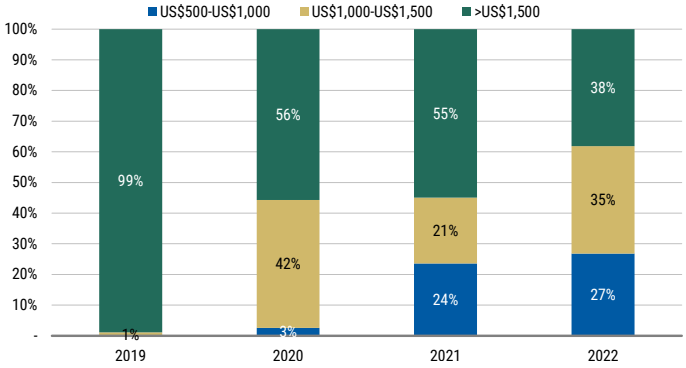
Looking at some major foldable smartphone models, the launch prices for the Samsung Galaxy Z Fold series have not changed that much at US$1,980, US$2,000, US$1,799 and US$1,799 for Z Fold, Z Fold 2, Z Fold 3 and Fold 4, respectively. On the other hand, the launch prices for its clamshell sibling Galaxy Z Flip have fallen over the years to US$1,380, US$1,499, US$999 and US$999 for Z Flip, Z Flip 2, Z Flip 3 and Z Flip 4, respectively.

Exhibit 45: Global Foldable Smartphone Price Range Breakdown - Unit Basis



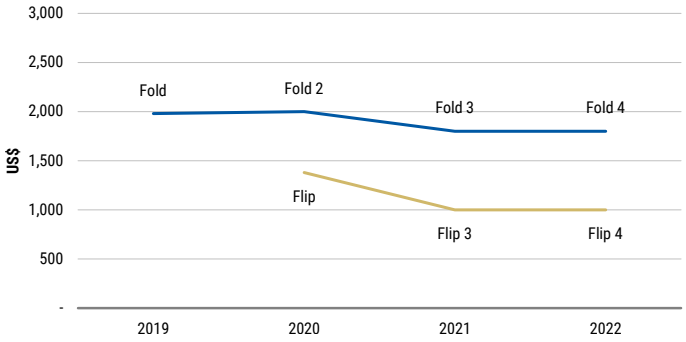
Source: IDC, Morgan Stanley Research

Exhibit 46: Global Foldable Smartphone Price Range Breakdown - Revenue Basis



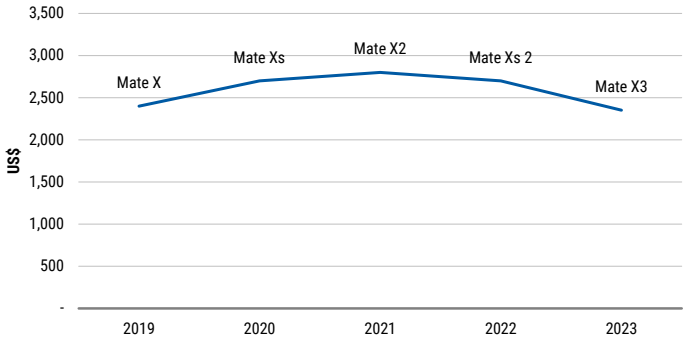
Source: IDC, Morgan Stanley Research

Exhibit 47: ASP Trend for Galaxy Z Fold and Flip Series



Source: Samsung, Morgan Stanley Research

Exhibit 48: ASP Trend for Huawei Mate X Series

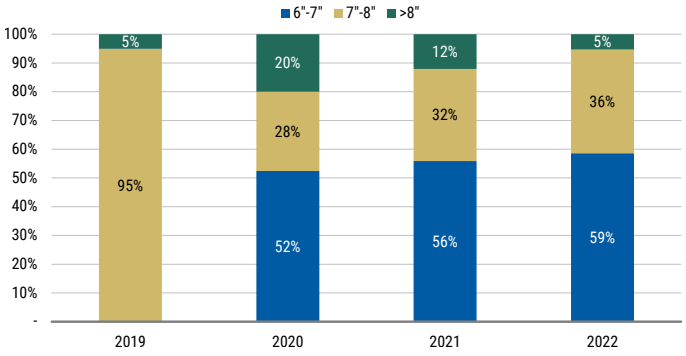


Source: Samsung, Morgan Stanley Research

Most Foldable Smartphones Equipped with 6"-8" Displays

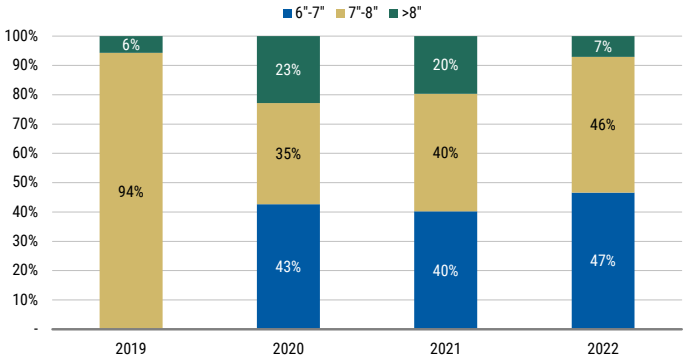
In 2022, 59% of global foldable smartphones were equipped with 6"-7" displays, 36% with 7"-8" displays and only 5% with displays above 8". In general, most of the clamshell models came in at 6"-7", while most of the book-type models were at 7"-8". As we mentioned earlier in this report, while the difference in the display size might not look that significant between the two form factors, the difference in the display area is actually considerable, owing to the difference in their aspect ratio.

Exhibit 49: Global Foldable Smartphone Size Breakdown - Unit Basis



Source: IDC, Morgan Stanley Research

Exhibit 50: Global Foldable Smartphone Size Breakdown - Revenue Basis



Source: IDC, Morgan Stanley Research

OLED and Micro LED Both Feasible Technologies

Currently, OLED is the only display technology that can enable the foldable design. However, longer term we believe that micro LED, dubbed the ultimate display technology, could also play a role here. We believe that leading suppliers could enjoy a first mover advantage and generate better margins in the first few years of proliferation owing to their better production yield and bigger scale, while latecomers try to catch up.

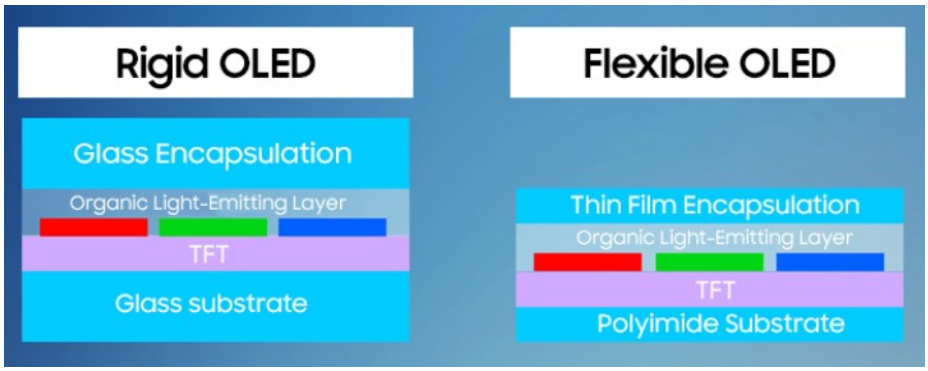
OLED the Current Enabler of Foldable Smartphones

From rigid to flexible OLED to foldable

In the early years of OLED display penetration into smartphones, display was manufactured on a glass substrate with another sheet of glass on the top of the structure to protect the organic light-emitting layers. At the CES 2013, Samsung introduced the flexible OLED display and commercialized this technology in the subsequent Galaxy Round model in October of the same year. The flexible OLED display replaced the glass substrate with a polyimide (PI) layer and used a thin film encapsulation process to form protective layers. Once both sheets of glass were removed, the OLED display could become flexible.

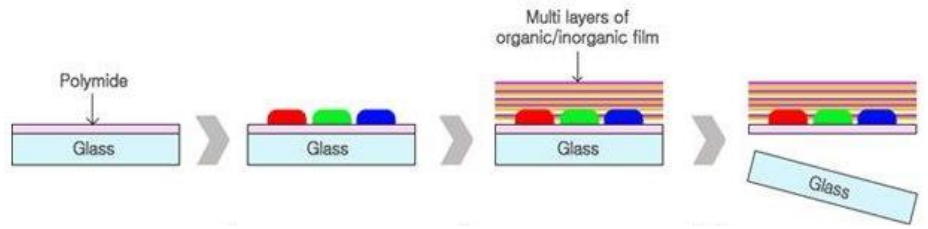
To move beyond being flexible to being foldable, the structure needs to be made much thinner, especially the supplementary films and layers, such as the polarizer, optically clear adhesive, and encapsulation.

Exhibit 51: OLED Structure - Rigid vs. Flexible



Source: Samsung Electronics

Exhibit 52: Manufacturing Process for Flexible OLED



Source: LG Display, Morgan Stanley Research

Chinese Players Catching up Quickly on Capacity

Given that the OLED display is self emissive without the backlight module and can be based on flexible substrates, it is pretty much the only feasible technology for the foldable display currently. Globally, the majority of the flexible OLED is owned by Korean and Chinese panel makers.

Samsung is the most aggressive promoter of OLED display and has been the early adopter of this technology since the first edition of the Galaxy S series in 2010. As a result, Samsung has dominated the supply of OLED in the past decade. On our estimates, it should still own 39% of the global flexible OLED capacity in 2022.

LG Display is also an early mover in the flexible OLED space, but due to its financial constraints, its capacity share was not that meaningful at 11% in 2022, according to our estimate.

BOE was a latecomer to the OLED space and started to ramp up its flexible OLED capacity from 2018, but it has been expanding quickly since then and should be ramping up its third Gen 6 flexible OLED fab this year. As of end-2022, we estimate BOE owned 25% of global capacity in 2022.

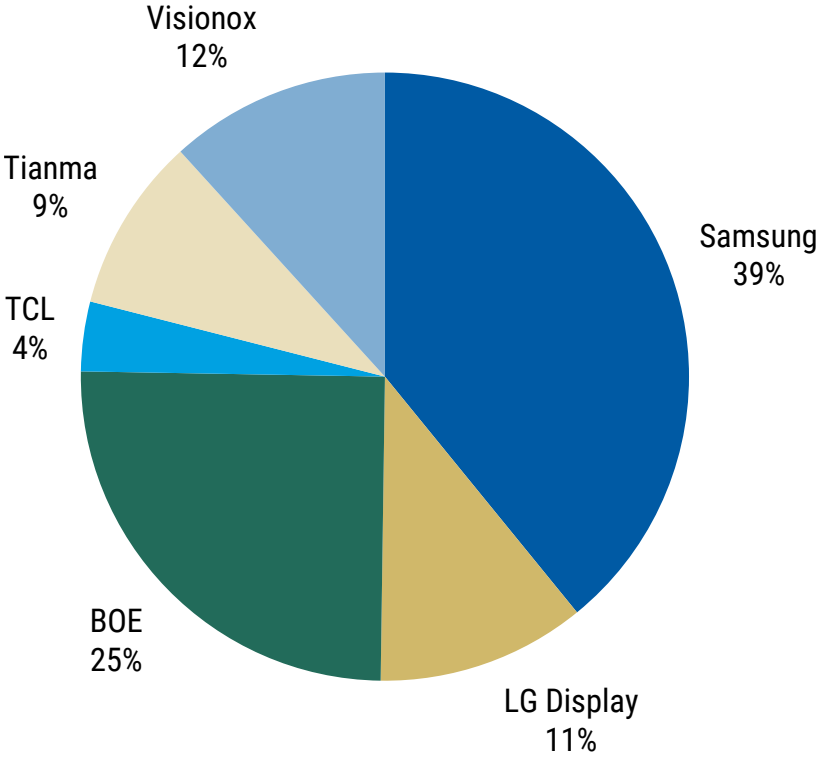
Other tier-two players in China, including TCL, Tianma and Visionox, are also gaining more traction in the flexible OLED market, with their 2022 capacity share reaching 4%, 9%, and 12%, respectively, according to our estimate.

Exhibit 53: Major Global Flexible OLED Capacity

Company	Fab	Gen	Capacity (K/mth)				
			2021	2022	2023E	2024E	2025E
Samsung	A3	6	124	114	106	105	105
Samsung	A4	6	30	30	30	30	30
Samsung	A5	6	10	15	15	15	15
LG Display	E5	6	15	15	15	15	15
LG Display	E6	6	30	30	30	30	30
BOE	B7	6	46	48	48	48	48
BOE	B11	6	30	44	48	48	48
BOE	B12	6	0	10	37	48	48
TCL	T4	6	15	15	23	41	45
Tianma	TM17	6	21	29	30	30	30
Tianma	TM18	6	0	8	15	16	16
Visionox	V2	6	15	25	30	30	30
Visionox	V3	6	2	20	30	30	30

Source: Omdia, Witsview, company data, Morgan Stanley Research (E) estimate

Exhibit 54: Global Flexible OLED Capacity Share



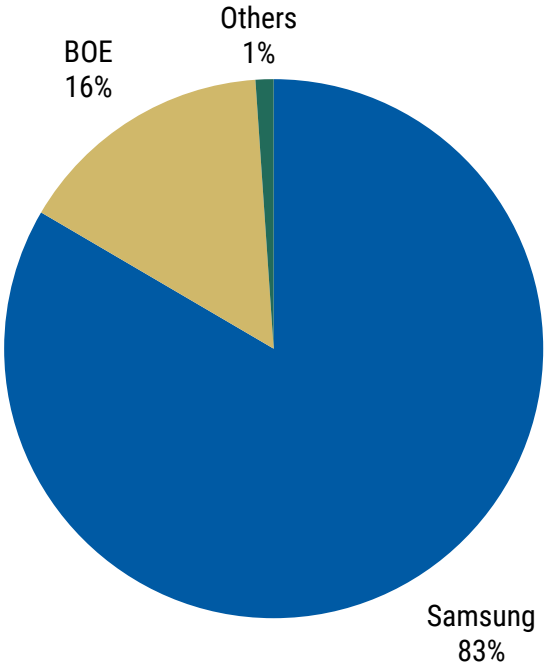
Source: Omdia, Witsview, Morgan Stanley Research estimates

Samsung Dominating the Supply of Foldable Display

Due to the limitations of the technological capabilities and differences in strategic focus, the foldable smartphone display supplier base is much more concentrated than the capacity suggests. Samsung dominated the market in 2022, representing 83% of shipments, buoyed by its position in the foldable smartphone end market and internal sourcing strategy. Outside of Samsung, BOE took the majority of the remaining shipments with a 16% share in 2022.

We expect the supplier structure to become more diversified with the increasing penetration of foldable smartphones and a bigger addressable market for panel makers in the coming years.

Exhibit 55: Global Foldable Smartphone Display Market Share (2022)



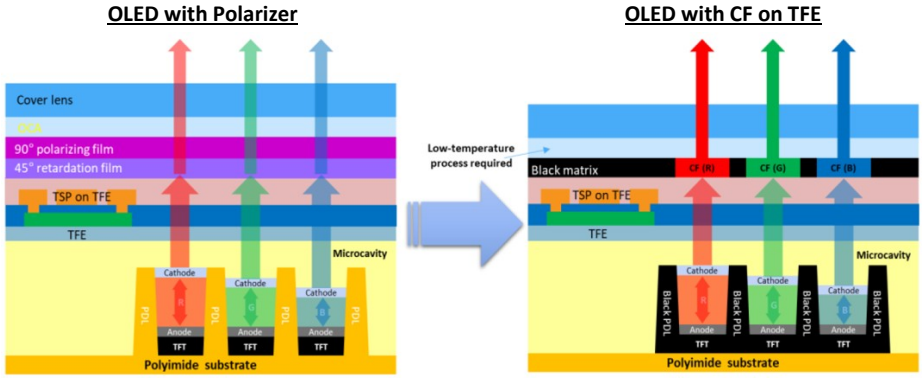
Source: Omdia, Morgan Stanley Research

Color Filter on Thin Film Encapsulation Adds Further Flexibility

In the mainstream OLED display structure, there is a polarizer layer on top of the display to block the reflected lighting from the electrode layer at the bottom of the display. In the Galaxy Z Fold 2 launched in 2020, Samsung adopted a new design called color filter (CF) on thin film encapsulation (TFE), or "CF on TFE", which uses a color filter and black matrix to perform a similar function to the polarizer (i.e., to reflect light). Samsung introduced CF on TFE because the structure can offer:

- **Higher brightness:** Since more light can pass through the layers and reach the surface of the display in the CF on TFE structure, it can offer 40-50% more brightness compared to the polarizer structure.
- **Better power consumption:** As the CF on TFE structure can lift transmittance to 68% vs. 43% for the polarizer structure, it can reduce power consumption by 25%.
- **Sharper contrast:** The contrast ratio can be 30% better in the CF on TFE structure vs. the polarizer structure.
- **Thinner structure:** The CF on TFE layer can be as thin as 5um vs. around 20-30um for the polarizer, so it can make the display more durable in the folding structure.
- **Improved color saturation:** The color filter can weed out the undesired wavelength from the reflected light and the emitted light, so it can further improve the color saturation of the OLED display.

Exhibit 56: Different OLED Structure

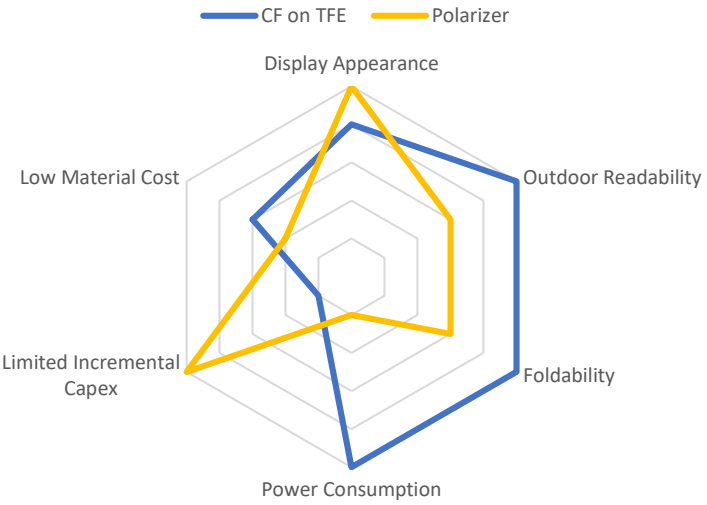


Source: Omdia

However, the CF on TFE structure also has some disadvantages, including:

- **Higher reflection rate:** Given that the color filter is less effective in blocking the reflected light, the OLED with the CF on TFE structure can achieve a reflection rate of 6.6% vs. 6.1% in the polarizer structure.
- **Additional investment:** Because traditional OLED fab does not have color filter manufacturing capabilities currently, it would require additional capex investment for the CF on TFE structure to be widely adopted.

Exhibit 57: Comparison of the CF on TFE and Polarizer Structures



Source: Omdia, Morgan Stanley Research

While there are some disadvantages to the CF on TFE solution, our checks indicate that Chinese panel makers are planning to manufacture more foldable smartphone displays using the CF on TFE structure, since its benefits seem to outweigh the disadvantages.

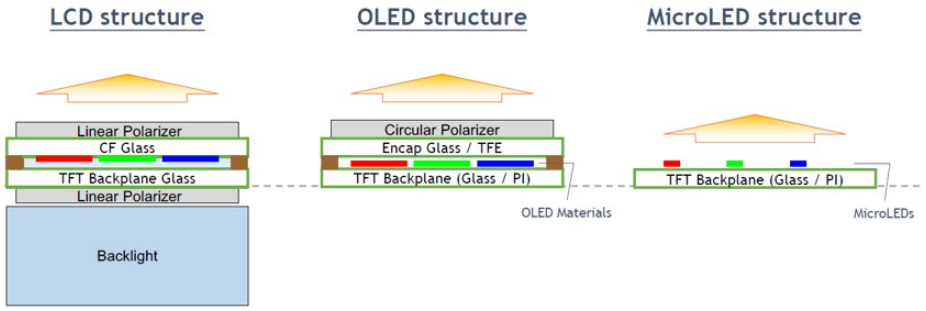
Micro LED a Potential Candidate in the Longer Term

Simpler Structure Ideal for Foldablility

Micro LEDs are chips with a dimension smaller than 0.075mm that are used to construct self-emissive displays instead of acting as the light source in a backlight module. The

technical structure for micro LED displays is different from that for traditional LCD displays. Without the need for a backlight module and most optical films, the structure of the micro LED is simpler than the LCD display. Furthermore, the micro LED display has a slimmer structure than its self-emissive counterpart OLED, as the former is built upon more durable inorganic materials. We believe that the simpler structure and better durability of micro LEDs could make it an ideal candidate for foldable devices compared to OLED.

Exhibit 58: Technical Structure for Different Display Technologies

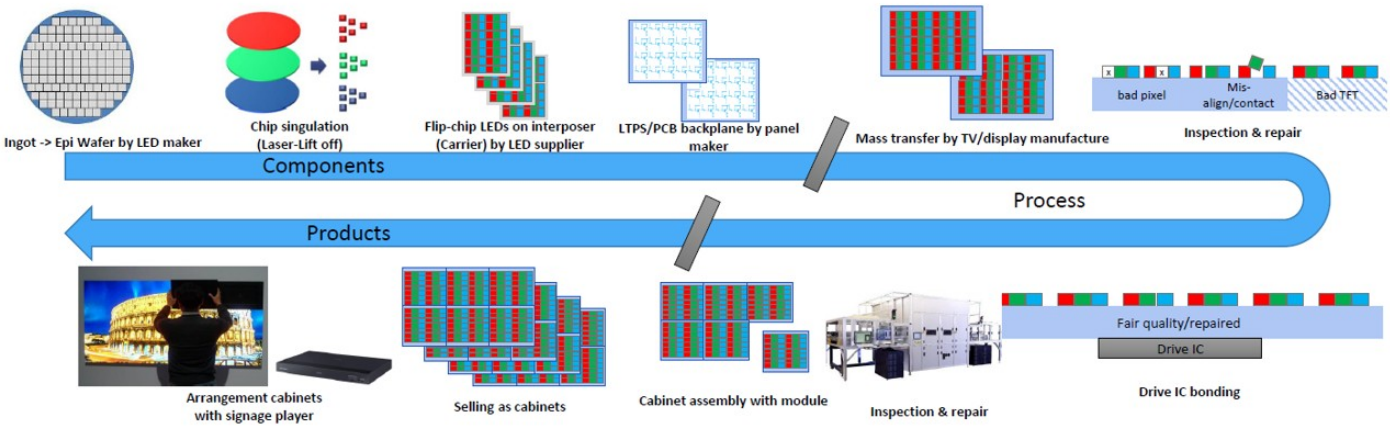


Source: Playnitride, Morgan Stanley Research

Micro LED Display Manufacturing Process

The manufacturing process of the micro LED display starts with LED chip manufacturing. Once red, green and blue micro LED chips are produced, they need to be moved onto the driving backplane, which could be a PCB or a glass array. The driving backplane with the red, green and blue micro LED chips bonded on then go through an inspection process to identify any malfunctioning sub pixels for repair or replacement. Micro LED displays are usually manufactured in the form of tiles to facilitate process control, but they can be assembled to form a bigger-size display with unnoticeable borders.

Exhibit 59: Micro LED Display - Manufacturing Process



Source: Omdia, Morgan Stanley Research

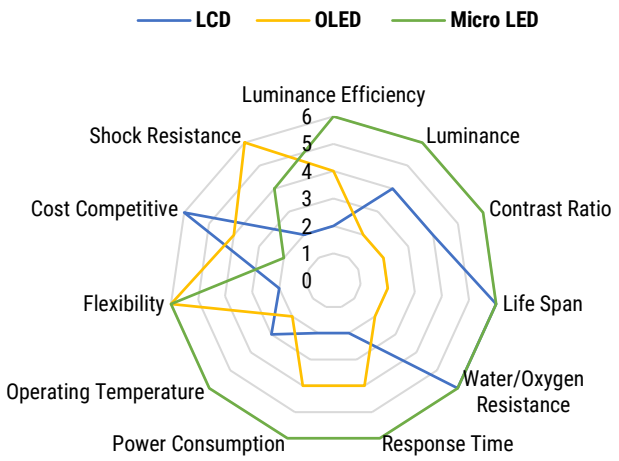
Potentially the "Ultimate" Display Technology

Micro LED is often dubbed the "ultimate" display technology by industry players, as it possesses a number of advantages over current mainstream technologies. Here, we focus

on the comparison of micro LED and OLED, two feasible technologies for foldable displays.

- **Better flexibility:** Though OLED can offer good flexibility as it is based on the polyimide substrate, the simpler structure for micro LEDs can enable better durability when it comes to foldablility, since it can prevent the risk of delamination.
- **Better luminance and power efficiency:** Though both are self-emissive displays, micro LED chips have better efficiency in converting electricity into light than the light emitting layers within OLEDs, so the former needs less power to deliver the same luminance as the latter.
- **Better durability and longer lifespan:** The micro LED display is based on inorganic materials and is thus less susceptible to moisture and oxygen, which can accelerate decay in the OLED display. Thus, the micro LED display can achieve a longer lifespan and be more durable in harsher operating environments.
- **Better transparency:** As the micro LED display has a smaller light emitting area vs. OLED, it can achieve a higher level of transparency, at >60%, vs. 30-50%, on average, for OLED.
- **Wide operating temperature:** The micro LED display can function normally at temperatures between minus 100 degrees celsius to positive 120 degrees celsius, vs. OLED's range of minus 30 degrees celsius to positive 70 degrees celsius.

Exhibit 60: Comparison of Properties for Different Display Technologies



Source: Omdia, Morgan Stanley Research

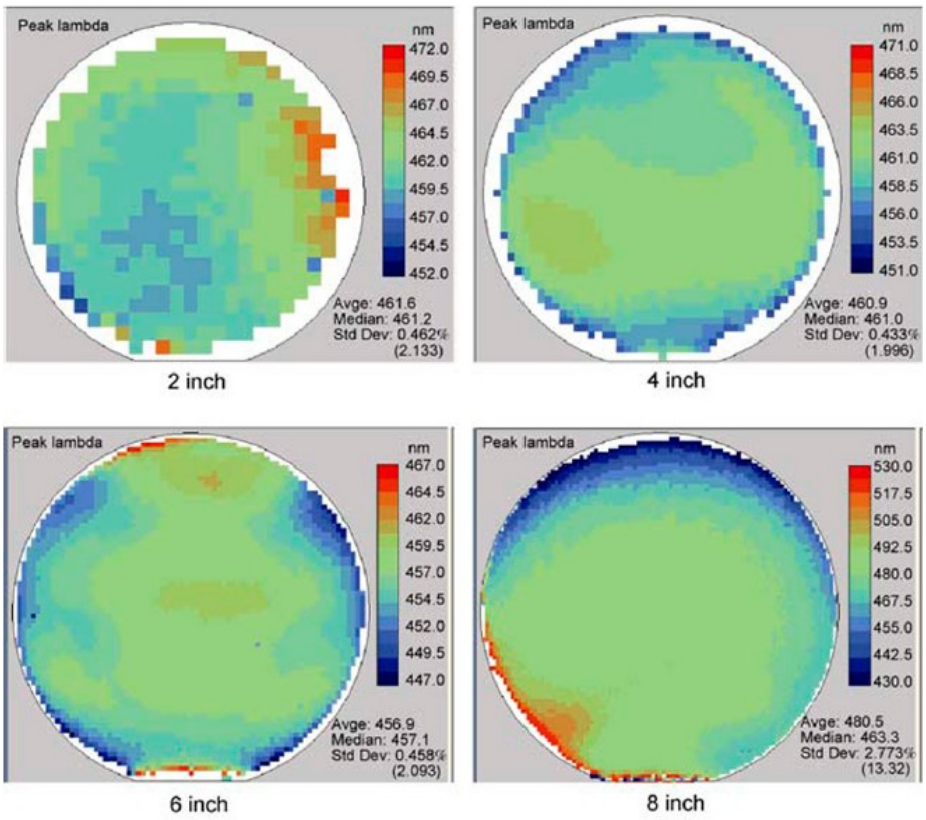
Hurdles for Commercialization of Micro LED

Despite all the benefits that micro LED can bring to the display market, there are currently just a few, very high-end, products that incorporate this technology, and full-scale commercialization still looks to be years away. While the mini display and the micro LED display use different technical configurations, the challenges they face share some similarities. However, the micro LED display is basically in another league regarding process complexity and cost, given the smaller size and larger volume of LED chips involved.

Better LED chip production yield needed

As LED chips become smaller, making it ever less economical to do sorting and binning post the chip manufacturing process, production yield will need to be tightly controlled, and based on a narrower wavelength deviation requirement. Our checks indicate that the wavelength of micro LED chips can only deviate from the designated wavelength by 3nm, while the traditional LED chips might deviate by up to 5nm. This difference could lead to production yields of 80-90% (5nm deviation) or 50-60% (3nm deviation) and impact whether or not micro LED will be widely adopted. In addition, the size of the wafer is also a variable, since it is, in general, more difficult to maintain uniformity on a larger size wafer.

Exhibit 61: Wavelength Uniformity and Wafer Size



Source: Morgan Stanley Research

Mass transfer not quick enough

After micro LED wafers are manufactured and tested, the chips that function normally are moved to a temporary backplane before being transferred and bonded to the backplane with the driving circuit. This process is usually called mass process, because the micro LED chips need to be transported en mass, instead of the one-by-one method in the traditional LED bonding process.

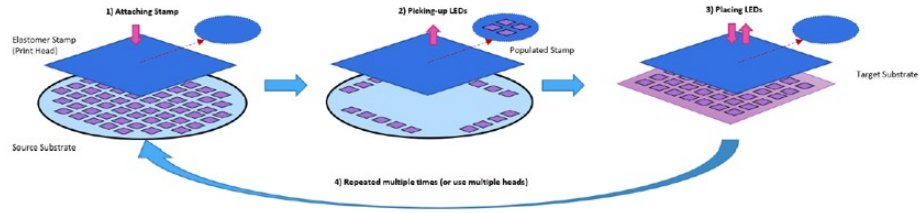
Currently, there are two major technologies used in the mass transfer process: the stamp method and the laser method.

- **Stamp method**
  - The elastomer stamp is used to strip the micro LED chips from the donor

substrate and place them on the receptor substrate by changing the speed at which the stamp is peeled from the substrates.
    - This method can handle micro LED chips with sizes over 20um
    - The throughput could reach 10-15mn units per hour
    - This is a more mature technology currently
- **Laser method**

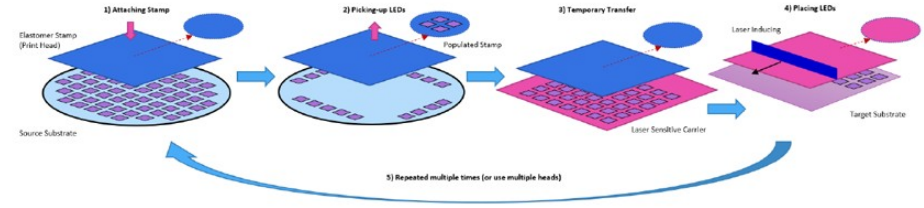
    - Micro LED chips are moved to a light-sensitive substrate, and a pulsed laser is used to remove the chips from the light-sensitive donor substrate and deposit them onto the receptor substrate
    - Since the contact point is equivalent to the size of the incident laser spot, it can handle micro LED chips down to a size of 5um
    - The throughput could be 65-70mn units per hour
    - This is an emerging technology that still needs to be proven

Exhibit 62: Mass Transfer - Stamp Method



Source: Omdia, Morgan Stanley Research

Exhibit 63: Mass Transfer - Laser Method

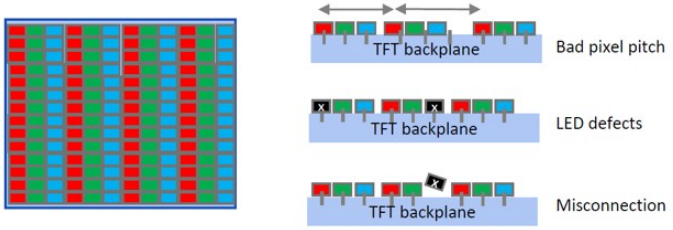


Source: Omdia, Morgan Stanley Research

Time-consuming repair process

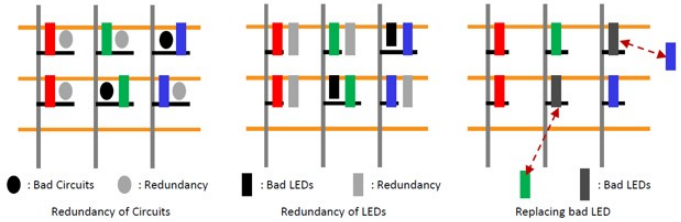
After the micro LED chips are transferred and bonded to the driving backplane, they need to be inspected again, since there could be multiple scenarios in which the display might not be in its optimal state. For example, the chips may deviate from their designated position, the chips might not deliver the right brightness and wavelength, or they are not properly bonded to the circuit. Thus, the micro LED bonded backplane will go through a repair process, where a properly functioning circuit/chip can be activated or where removal/replacement is conducted.

Exhibit 64: Micro LED Defect Types



Source: Omdia, Morgan Stanley Research

Exhibit 65: Micro LED Repair Methods



Source: Omdia, Morgan Stanley Research

Considering the number of micro LED chips needed for a display and the requirement of almost no black pixels, the repair process can be time consuming. Taking the mainstream 7"-8" foldable display as an example, if we assume the bonding yield to be 99.99%, there could still be 1,000-2,000 defects, depending on the resolution, which might take 3-5 hours to repair, at a pace of 10 seconds per defect.

Exhibit 66: Estimated Time for Repairing Micro LED Pixels

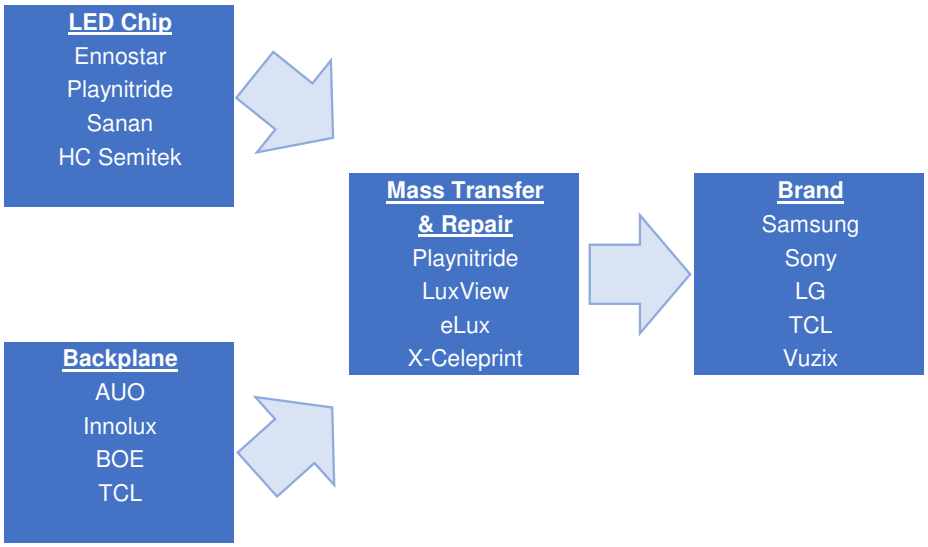
Display Size	Resolution		# of Subpixels	Yield (%)	# of Defects	Repair Time (Hours)	
	X	Y				60 Sec/Defect	10 Sec/Defect
7.1"	1920	1792	10,321,920	99.99%	1,032	17	3
7.6"	2176	1812	11,828,736	99.99%	1,183	20	3
7.85"	2496	2224	16,653,312	99.99%	1,665	28	5
7.92"	2344	2156	15,160,992	99.99%	1,516	25	4
8.03"	2160	1916	12,415,680	99.99%	1,242	21	3

Source: Morgan Stanley Research

Supply Chain Players for Micro LED Displays

On top of the traditional LED chip manufacturers and the panel makers, there are several start-ups focused on the critical mass transfer and repair process. Playnitride (6854.TW, not covered), for example, is a firm dedicated to micro LED development, including epi wafer, chip process, mass transfer, inspection and repair, and it supplies several leading brands.

Exhibit 67: Micro LED Display Supply Chain



Source: Morgan Stanley Research

More products to be brought to market, but more meaningful volume will take time

On top of the TV and public display applications that are adopting micro LED technology for the premium segment, we expect to see wearable devices also leverage the advantages of micro LED. However, we believe it will take a few more years for the supply chain to optimize the materials, components and processes, before it is ready to bring this to the foldable space.

Dynamics in Other Relevant Components

Cover Lens - Ultra Thin Glass Dominates

Similar to the regular smartphone, the foldable smartphone laminates a cover on top of the display to protect it from external damage, such as scratches. However, the mainstream solution used in the regular smartphone is rigid in nature, so it cannot be incorporated into the foldable model.

Colorless polyimide (CPI) is one of the materials that can be used as the cover lens for foldable smartphone, since it is flexible and has good optical properties. However, it is soft in nature and susceptible to scratches, so the layer will need to be made thicker and there is usually an additional hard coating layer required to improve its surface flatness, texture feel and scratch resistance.

Ultra thin glass (UTG) is another feasible material for the cover lens. The inherent properties of UTG are quite different from CPI. UTG has good scratch resistance, but poor shock resistance, so an additional layer of PET is often added to absorb the shock. Meanwhile, it can offer a more solid feel on a more even surface, but that comes at the expense of a bigger bending radius.

Currently, UTG is the taking a bigger share in the global foldable smartphone market on a unit basis, given that Samsung has adopted this solution, while Huawei and Honor still prefer CPI for their foldable devices.

Exhibit 68: Comparison of Cover Lens for Foldable Smartphones

Cover Lens Solutions	UTG	CPI
Shock/Drop Resistance	☺	☺☺☺
Scratch Resistance	☺☺☺	☺
Optical Transmittance	☺☺☺	☺☺
Bending Radius	☺☺	☺☺☺
Texture/Feel	☺☺☺	☺
Thickness	☺☺☺	☺☺
Cost	☺☺	☺☺☺

Source: Omdia, Morgan Stanley Research. Note: more smiley faces means more favorable characteristics

In the UTG supply chain, the raw glass is supplied by traditional display glass vendors including Coring, AEG, NEG, and Schott, who use their proprietary recipe to form the glass sheet and then further strengthen the surface of the glass with the ion exchange process. The raw glass then goes through the cutting, grinding, second chemical strengthening and inspection process done by the UTG backend partners, such as Qowoo, and eCONY.

In the CPI supply chain, suppliers like Kolon, Sumitomo Chemical, and SKC provide the CPI materials and players like DNP, MSK, and Songwoo provide the hard coating process.

Some CPI vendors such as SKC and LG Chemical, also have their own hard coating process to offer an integrated solution.

Exhibit 69: UTG Supply Chain Players

UTG Raw Glass	UTG Finisher
Schott (Advanced)	Dowoo insys
Corning (Advanced)	eCONY
NEG	Lens Tech, Biel, Token, Kaimao, etc.
AGC	
Schott (Regular)	
Corning (Regular)	

Source: Omdia, Morgan Stanley Research

Exhibit 70: CPI Supply Chain Players

CPI Suppliers	Hard Coating Suppliers
Kolon	DNP, MSK
Sumitomo Chem	Songwoo
SKC	SKC
SK Innovation	SK Innovation, HughStar
LG Chem	LG Chem

Source: Omdia, Morgan Stanley Research

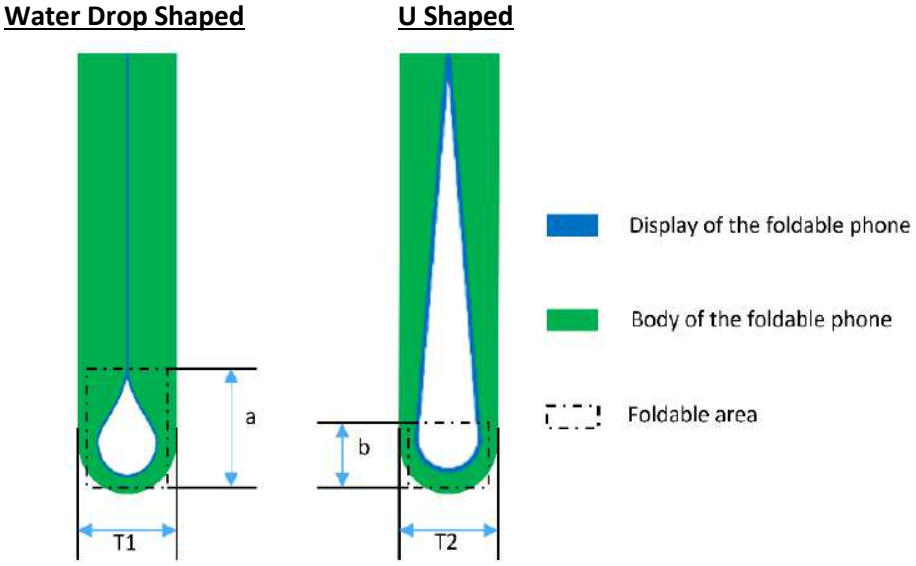
Hinge: Water Drop-Shaped Design Gaining Popularity

The hinge is one of the important components in the foldable smartphone, given that it can impact the size and look of the phone. There are two mainstream designs currently, including the U-shaped hinge and the water drop-shaped hinge.

Compared to the more traditional U-shaped hinge design, the water drop-shaped hinge can offer a less visible gap when the device is fully folded, which means a slimmer form factor and sleeker appearance, in our opinion. However, this could come with a price tag, as the display will need to have higher curvature in the water drop-shaped design, which might compromise the durability and reliability of the display to some extent over time, as the display needs to withstand relatively more tension and compression than the U-shaped design.

Our checks indicate that Samsung has shifted to the water drop shape design in its latest model vs. U shape design in the past.

Exhibit 71: Different Hinge Design for Foldable Smartphones



Source: Omdia, Morgan Stanley Research

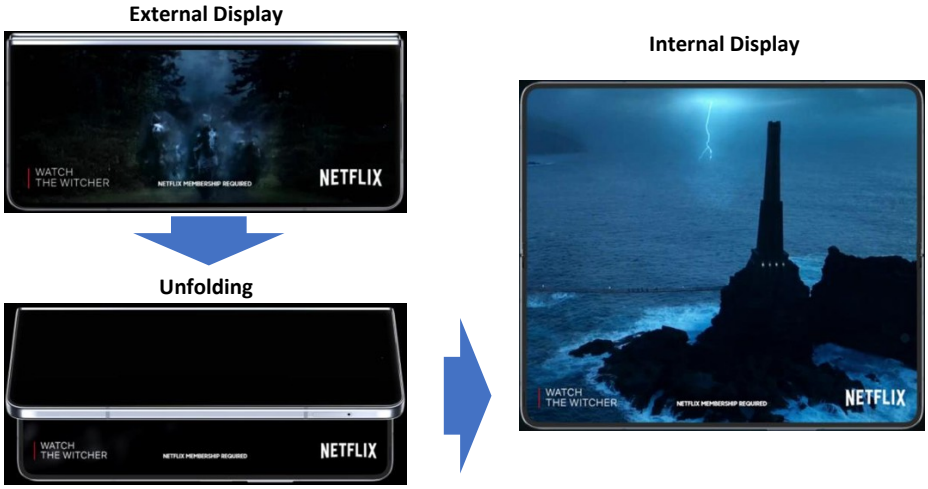
Software - Optimization Critical to User Experiences

Despite the significant hardware spec upgrade taking place currently, especially on the display side, we believe that most of the software will need to be tailored to make best use of the incremental display. On this front, we think there are a few areas worth highlighting.

Screen continuity

Given that foldable smartphones usually have one smaller size external display when folded and one bigger internal display when unfolded, it's important for the software to deliver a seamless transition between these two. This will be crucial in a typical scenario where a user checks a message or notification on the external display with the smartphone folded and then unfolds the device to read more content or give a more comprehensive response.

Exhibit 72: Concept of Screen Continuity on Foldable Smartphones

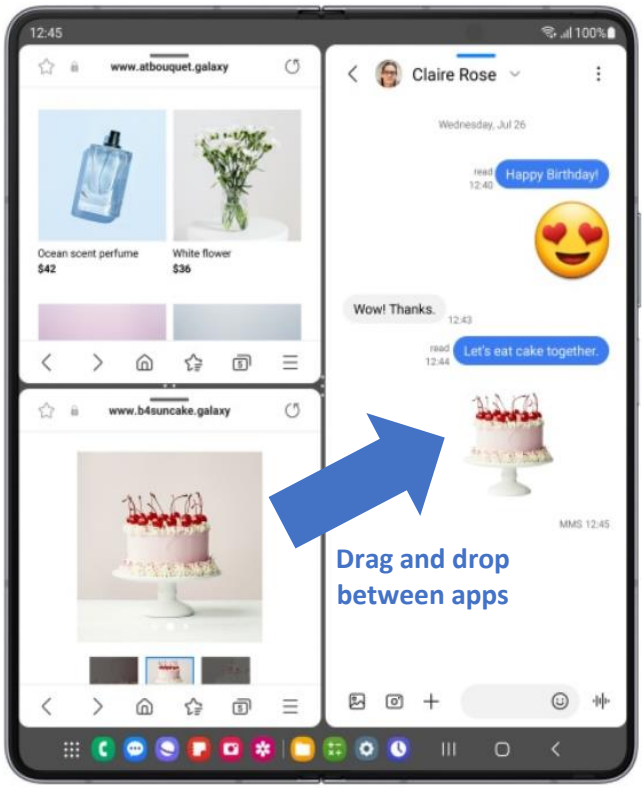


Source: Samsung, Morgan Stanley Research

Multiple windows

To fully leverage the extra display space in the foldable smartphone, it seems inevitable for the software to support multiple windows for multiple apps. Moreover, the interactions and the data transfer between apps should be achieved in an intuitive way. For example, it would be convenient for users if, in the multiple-window setup, the user can drag and drop a picture just taken or found on the internet and transfer it to a friend through an instant messenger app.

Exhibit 73: Multiple-window Setup Enabling an Intuitive User Experience



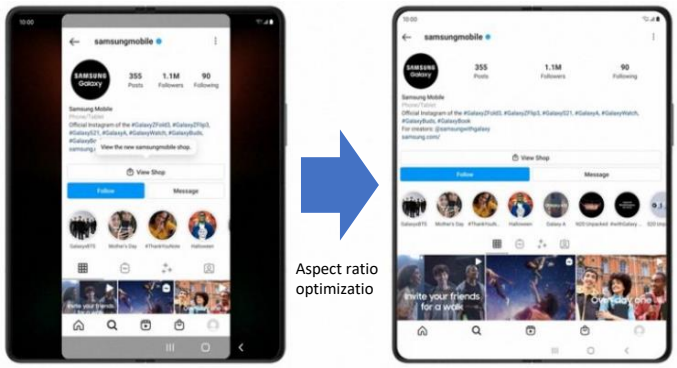
Source: Samsung, Morgan Stanley Research

Aspect ratio adjustment

- The more basic level of optimization is for the app to match the aspect ratio of the unfolded display, which is usually more close to a square shape (e.g., aspect ratio of 22:23) vs. the regular smartphone display, which is usually closer to a rectangle shape (e.g., an aspect ratio of 18:9). If the app is not designed to be compatible with a foldable smartphone, it could leave big margins on both sides of the display that go unused.

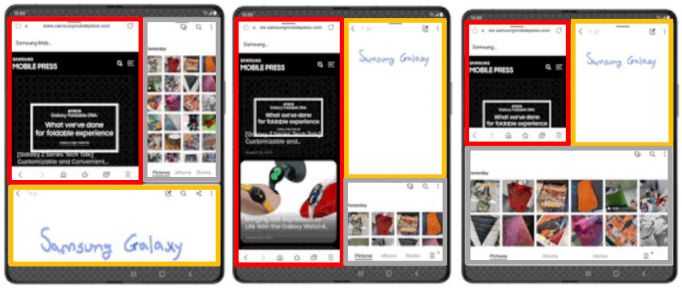
- In addition, a more advanced level of optimization is for the app to change the aspect ratio quickly depending on the use case scenario. For example, the aspect ratio would be quite different for a full screen display of one app vs. the same app in a multiple-window set up, or when you partially fold the device to let it stand by itself to take a selfie.

Exhibit 74: Aspect Ratio Optimization for Apps



Source: Samsung, Morgan Stanley Research

Exhibit 75: Flexible Adjustment of the Aspect Ratio in Muti-window Setup



Source: Samsung, Morgan Stanley Research

Software optimization for foldable smartphones will likely depend on the efforts of both the brand and the app developer, in our view. This could be a chicken-and-egg situation, especially for app developers, since the bigger the installed base for foldable smartphones, the more economic sense it makes for the developer to optimize the app for the unique use case scenario. We thus expect this to continue evolving for better use experiences in the years ahead.

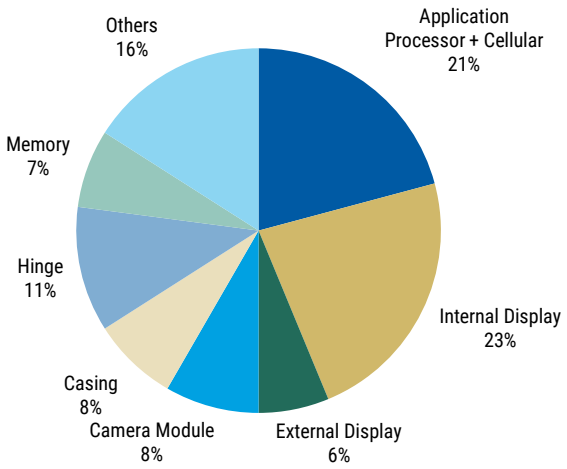
Display Accounts for 29% of BOM for Foldable Smartphone

We have analysed the bill of materials (BOM) for the mainstream book-type foldable smartphone model to break down the costs of the key components for the device.

On our estimates, the display accounts for 29% of the total BOM cost, with 23% for the internal foldable display and another 6% for the external regular display. The application processor adopted by the foldable should be the most high end available, given the premium positioning of the device, so we estimate that the application processor will account for 21% of the BOM cost. Another key component is the mechanical parts, especially the casing and hinge, which we think could account for 19% of the BOM cost.

These three major components combined - display, application processor and mechanical parts - account for 69% of the total BOM cost for a typical book-type foldable smartphone device. Though the application processor is the second most expensive component in the foldable device, it's actually made for high-end smartphone models, regardless of whether it is foldable or not, so the components that are more unique in foldable devices are the display and the hinge. We thus believe that relevant suppliers in those supply chains stand to benefit more from the increasing popularity of foldable smartphones.

Exhibit 76: BOM Cost Breakdown of Typical Book-type Foldable Smartphones



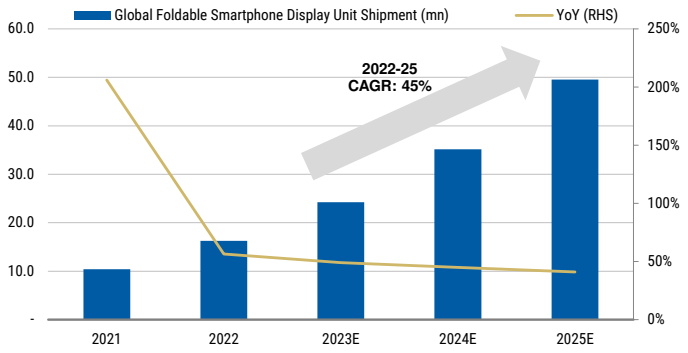
Source: Omdia, Witsview, Morgan Stanley Research estimate

Foldable Smartphone Display Growing at a 45% CAGR in 2022-25e

Foldable Displays to Reach 7% of OLED Shipment in 2025e

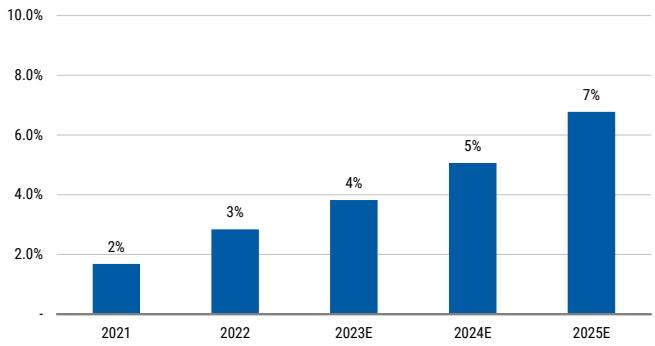
According to the data from Omdia, the total shipment of foldable displays was 16.3mn units in 2022, or 2.8% of the global OLED shipment. With more smartphone brands launching foldable smartphone models and the ecosystem becoming more mature, we estimate foldable smartphone shipments will increase at a 45% CAGR in the coming three years to reach 49.5mn units in 2025. This would represent 6.8% of total OLED smartphone shipments.

Exhibit 77: Global Foldable Smartphone Display Unit Shipment



Source: Omdia, Morgan Stanley Research (E) estimate

Exhibit 78: Foldable Smartphone Penetration into OLED Smartphone Display - Unit Basis



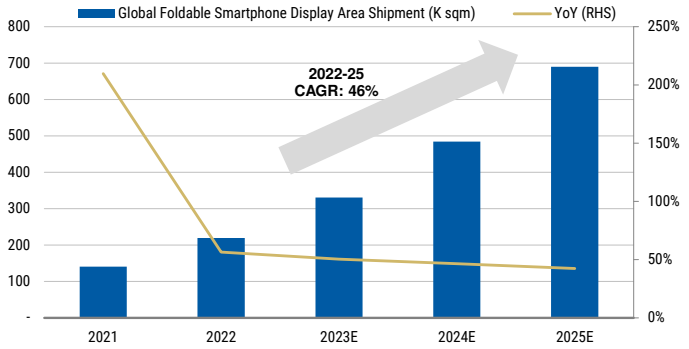
Source: Omdia, Morgan Stanley Research (E) estimate

Foldable Displays to Account for 9% of OLED Display Area in 2025

As the book-type foldable display is much larger than the mainstream smartphone display and it takes a share of around 40% in the total foldable market, we think it's reasonable to expect that foldable display represented a bigger portion of smartphone OLED display shipments on an area basis than on a unit basis.

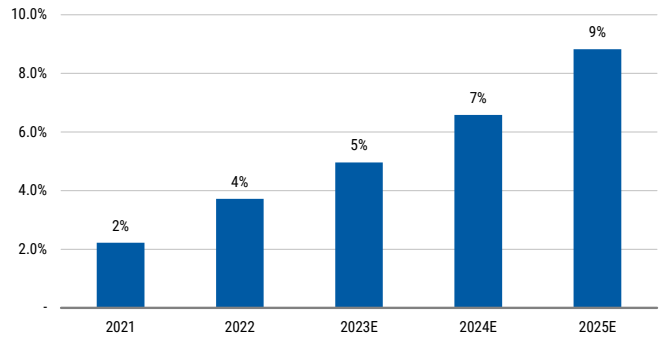
Per Omdia data, foldable displays shipment area reached 220,000 square meters in 2022, accounting for 3.7% of the total OLED display area in 2022. We estimate that it could grow at a three-year CAGR of 46% to 690,000 square meters in 2025, or 8.8% of the global OLED display area.

Exhibit 79: Global Foldable Smartphone Display Area Shipment



Source: Omdia, Morgan Stanley Research (E) estimate

Exhibit 80: Foldable Smartphone Penetration into OLED Smartphone Display - Area Basis

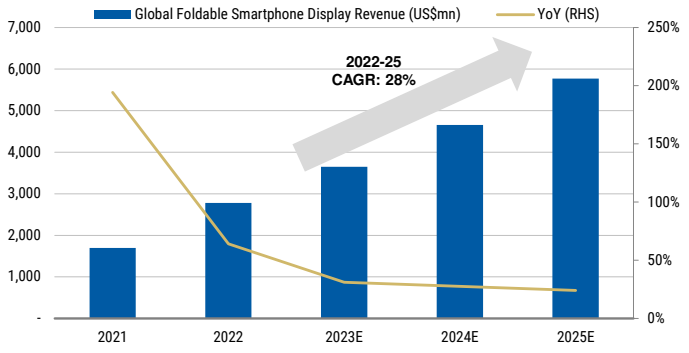


Source: Omdia, Morgan Stanley Research (E) estimate

16% of OLED Smartphone Display Revenue from Foldable in 2025e

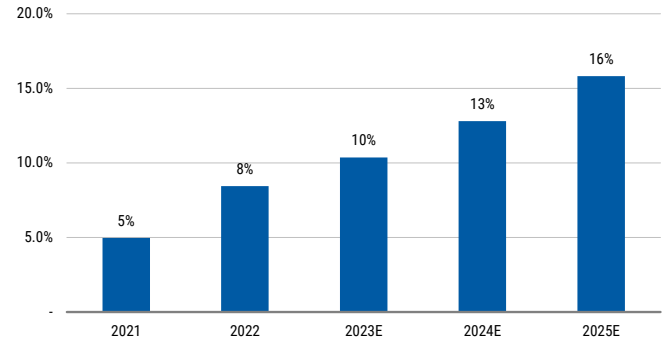
In 2022, foldable smartphone displays generated US$2.9bn of revenue globally, representing 8.4% of total OLED smartphone display revenue at US$32.9bn. Under the assumption of 12% ASP decline per year, we estimate that total foldable smartphone display revenue will hit US$5.8bn in 2025, which implies a three-year CAGR of 28% and would contribute 15.8% of total OLED smartphone display revenue.

Exhibit 81: Global Foldable Smartphone Display Revenue



Source: Omdia, Morgan Stanley Research (E) estimate

Exhibit 82: Foldable Smartphone Penetration into OLED Smartphone Display - Revenue Basis



Source: Omdia, Morgan Stanley Research (E) estimate

Potential Risks to Our Forecasts

Upside risks

- More aggressive stance from major smartphone brands, especially those not joining the camp yet, in promoting or launching foldable smartphone models
- Faster reductions in component costs bring down selling prices
- Better user experiences, offering seamless integration of hardware and software, prompt more users to migrate from regular smartphones

Downside risks

- Challenging macro environment negatively impacts overall demand for consumer electronics
- Slower progress in component performance leads to a less satisfactory user experience

More Possibilities Ahead

The current foldable smartphones still have room for optimization, and the supply chain is already exploring possible design concepts that could draw more attention and make the smartphone even more versatile in use cases. Below we list a few of these new architectures in the order of technology readiness.

Multiple-fold Displays

The multiple-fold display allows the smartphone to spread out into an even larger display (e.g., 8.x" or 12.x") than the current book-type foldable display. There are two configurations to embody this:

- **G-type folding:** both sides of the display can be folded either inward or outward to form the G shape from the top view
- **S-type folding:** one side of the display is folded inward and the other folded outward, forming the S shape from the top view

Exhibit 83: Different Types of Multiple-fold Displays

G Type Folding **S Type Folding**

Source: Omdia, Morgan Stanley Research

The multiple-fold structure to some extent magnifies the benefits of the current foldable version, as it allows an even bigger display area when the screen is fully unfolded. Nonetheless, this comes with incremental challenges, such as the additional folding area where malfunctions tend to occur, the manufacturing yield and cost of the larger-size flexible OLED display, and the choice of cover lens materials in the S-type design given the different bending radius in the in-folding and out-folding structures.

Exhibit 84: Pros and Cons of Different Multiple-Fold Displays

	G Type Folding		S Type Folding
	Inward	Outward	
Device Thickness	☺☺☺	☺	☺☺
Bendign Radius	☺☺☺	☺☺	☺☺
Cover Lens Choice	☺☺☺	☺☺	☺☺
Additional External Display	☺☺	☺☺☺	☺☺☺
Protection of Internal Display	☺☺☺	☺☺	☺

Source: Omdia, Morgan Stanley Research. Note: more smiley faces means more favorable characteristics

On top of the G type and S type designs, there is another structure sometimes referred to as the multiple-fold structure. In this structure, there is only one folding area, but the display can be folded either inward or outward at the user's will. This design definitely adds more flexibility, but since the material requirement is quite different in the inward folding and outward folding structure, it can be challenging to enable a 360-degree folding motion. On this front, Samsung showcased one prototype called Flex In & Out in CES 2023, but there is no clear timetable for this to be commercialized yet.

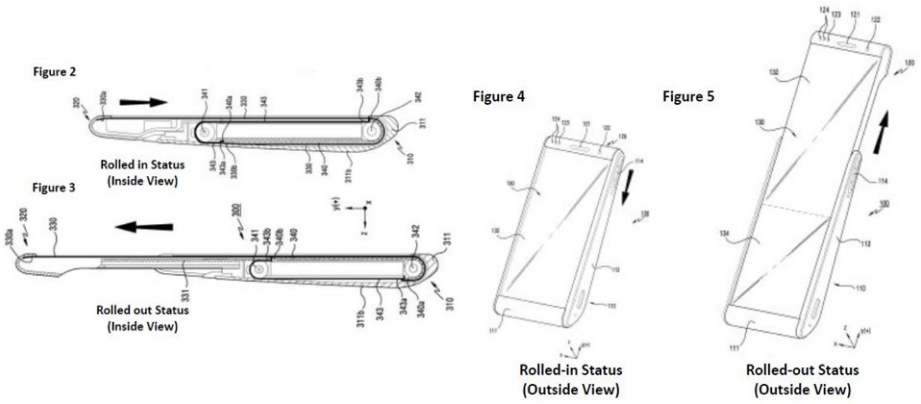
Exhibit 85: Samsung Flex In & Out Foldable Display

Source: Omdia, Morgan Stanley Research

Rollable Display

Besides folding the displays to change the sizes in different use cases, a similar purpose can be achieved by wrapping and expanding a certain part of the display. In Exhibit 66, we can see two simple diagrams for the devices with a rollable display.

Exhibit 86: Concept of Rollable Displays



Source: Omdia, Morgan Stanley Research

Though both foldable and rollable displays are based on flelxible displays, they could have different advantages and disadvantages, since they are configured in different mechanical structures.

Advantages for rollable displays vs. foldable displays

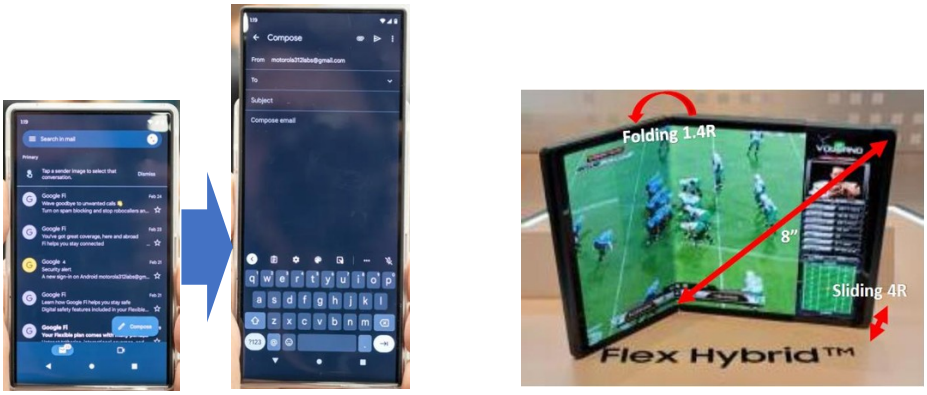
- **No crease:** Since there is no folding area on the display, there won't be a crease there, which has been one of the key issues that the supply chain wants to get rid of
- **Less risk of delamination:** Given that the display is partially wrapped, instead of folded, the stack of layers is less susceptible to delamination due to less tension and compression occurring at the deformation area
- **Larger bending radius:** Compared to the foldable display, which has a bending radius of 5mm or less, the rollable display can accept a larger bending radius, which may lead to a loosened requirement on the thickness of the layers.

Challenges for rollable displays vs. foldable displays

- **More components required:** One motor and some mechanical parts might be needed to support the sliding mechanism, which could be another source of durability issues. In addition, it could take up space, making the device more bulky, and consume more power
- **Achieving water resistance will be more difficult:** The movable mechanical parts make it less easy to achieve the same level of water resistance as the foldable device.

Exhibit 87: Roller Smartphone Samples

Motorola **Samsung**



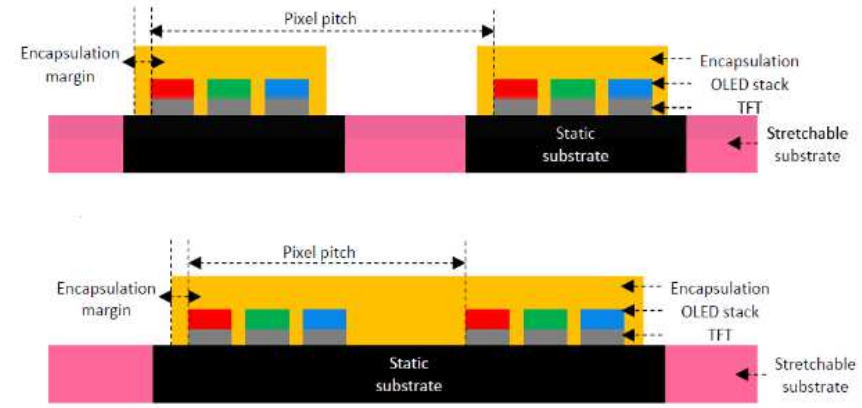
Source: Omdia, Morgan Stanley Research

Stretchable Display

Stretchable display is probably the least feasible design of the transformable display structures currently, given the current OLED display's limited stretchability. Our checks indicate that flexible OLED display can be stretched by only 5-10%, while the next generation of display technology, micro LED, can theoretically be stretched by 30-40%.

Exhibit 88: Concept of Stretchable Displays

OLED Display



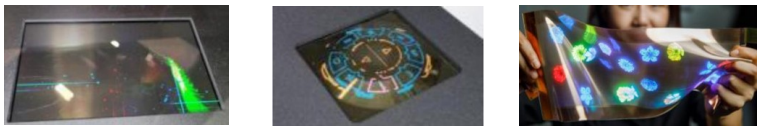
Micro LED Display

Source: Omdia, Morgan Stanley Research

Some panel makers have showcased samples of the stretchable display, including AU Optronics and LG Display, based on the micro LED structure. Although stretchable display can be useful in many applications, including portable devices, wearable devices, and

automobiles, the micro LED display itself seems to have room for improvement, as we have discussed earlier in this report. In our view, more effort and resources need to be devoted to this space before we can see stretchable display gain more traction in the real world.

Exhibit 89: Prototypes of Stretchable Dipslays



Manufacturer	AUO	AUO	LGD
Size	6.45"	3.5"	12"
Resolution	900*540	350*350	1080*540
Dpi	141	141	100
Backplane	LTPS	LTPS	LTPS
Stretchability	<5%	<5%	20%
Durability	100K iterations	100K iterations	10K iterations

Source: Omdia, Morgan Stanley Research

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Global Stock Ratings Distribution

(as of July 31, 2023)
The Stock Ratings described below apply to Morgan Stanley's Fundamental Equity Research and do not apply to Debt Research produced by the Firm.
For disclosure purposes only (in accordance with FINRA requirements), we include the category headings of Buy, Hold, and Sell alongside our ratings of Overweight, Equal-weight, Not-Rated and Underweight. Morgan Stanley does not assign ratings of Buy, Hold or Sell to the stocks we cover. Overweight, Equal-weight, Not-Rated and Underweight are not the equivalent of buy, hold, and sell but represent recommended relative weightings (see definitions below). To satisfy regulatory requirements, we correspond Overweight, our most positive stock rating, with a buy recommendation; we correspond Equal-weight and Not-Rated to hold and Underweight to sell recommendations, respectively.

	Coverage Universe		Investment Banking Clients (IBC)			Other Material Investment Services Clients (MISC)	
Stock Rating Category	Count	% of Total	Count	% of Total IBC	% of Rating Category	Count	% of Total Other MISC
Overweight/Buy	1347	37%	276	43%	20%	609	39%
Equal-weight/Hold	1659	46%	294	46%	18%	717	46%
Not-Rated/Hold	3	0%	0	0%	0%	1	0%
Underweight/Sell	604	17%	69	11%	11%	227	15%
Total	3,613		639			1554	

Data include common stock and ADRs currently assigned ratings. Investment Banking Clients are companies from whom Morgan Stanley received investment banking compensation in the last 12 months. Due to rounding off of decimals, the percentages provided in the "% of total" column may not add up to exactly 100 percent.

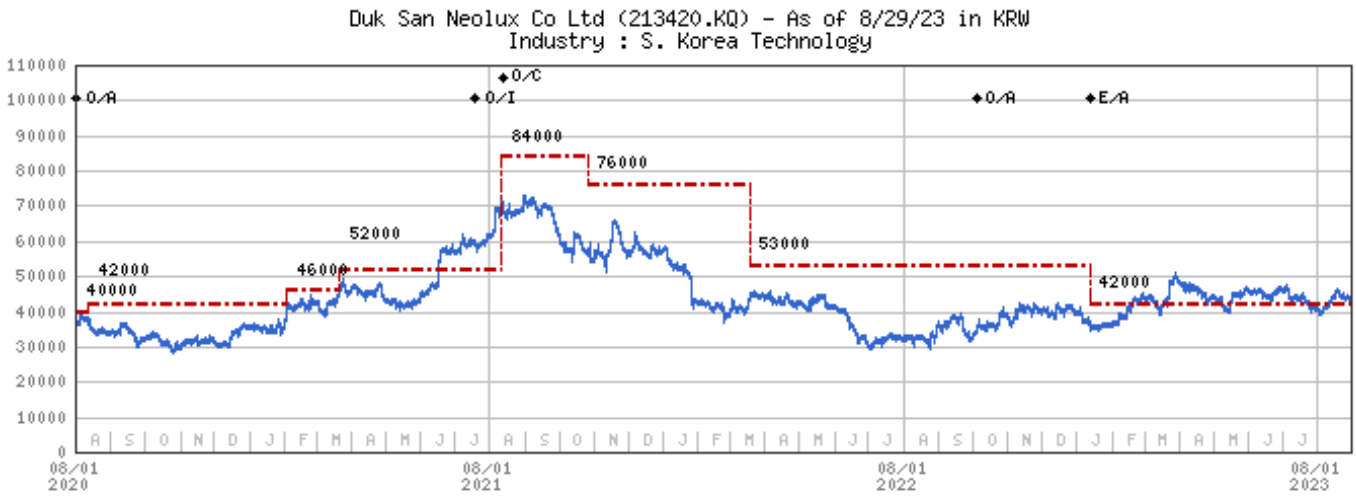
Analyst Stock Ratings

Overweight (O). The stock's total return is expected to exceed the average total return of the analyst's industry (or industry team's) coverage universe, on a risk-adjusted basis, over the next 12-18 months.
Equal-weight (E). The stock's total return is expected to be in line with the average total return of the analyst's industry (or industry team's) coverage universe, on a risk-adjusted basis, over the next 12-18 months.
Not-Rated (NR). Currently the analyst does not have adequate conviction about the stock's total return relative to the average total return of the analyst's industry (or industry team's) coverage universe, on a risk-adjusted basis, over the next 12-18 months.
Underweight (U). The stock's total return is expected to be below the average total return of the analyst's industry (or industry team's) coverage universe, on a risk-adjusted basis, over the next 12-18 months.
Unless otherwise specified, the time frame for price targets included in Morgan Stanley Research is 12 to 18 months.

Analyst Industry Views

Attractive (A): The analyst expects the performance of his or her industry coverage universe over the next 12-18 months to be attractive vs. the relevant broad market benchmark, as indicated below.
In-Line (I): The analyst expects the performance of his or her industry coverage universe over the next 12-18 months to be in line with the relevant broad market benchmark, as indicated below.
Cautious (C): The analyst views the performance of his or her industry coverage universe over the next 12-18 months with caution vs. the relevant broad market benchmark, as indicated below.
Benchmarks for each region are as follows: North America - S&P 500; Latin America - relevant MSCI country index or MSCI Latin America Index; Europe - MSCI Europe; Japan - TOPIX; Asia - relevant MSCI country index or MSCI sub-regional index or MSCI AC Asia Pacific ex Japan Index.

Stock Price, Price Target and Rating History (See Rating Definitions)



Stock Rating History: 8/1/18 : /C; 7/30/19 : /I; 11/18/19 : /A; 4/9/20 : O/A; 7/19/21 : O/I; 8/12/21 : O/C; 10/4/22 : O/A; 1/12/23 : E/A

Price Target History: 4/9/20 : 40000; 8/12/20 : 42000; 2/3/21 : 46000; 3/22/21 : 52000; 8/11/21 : 84000; 10/26/21 : 76000; 3/18/22 : 53000; 1/12/23 : 42000

Source: Morgan Stanley Research Date Format : MM/DD/YY Price Target No Price Target Assigned (NA)

Stock Price (Not Covered by Current Analyst) Stock Price (Covered by Current Analyst)

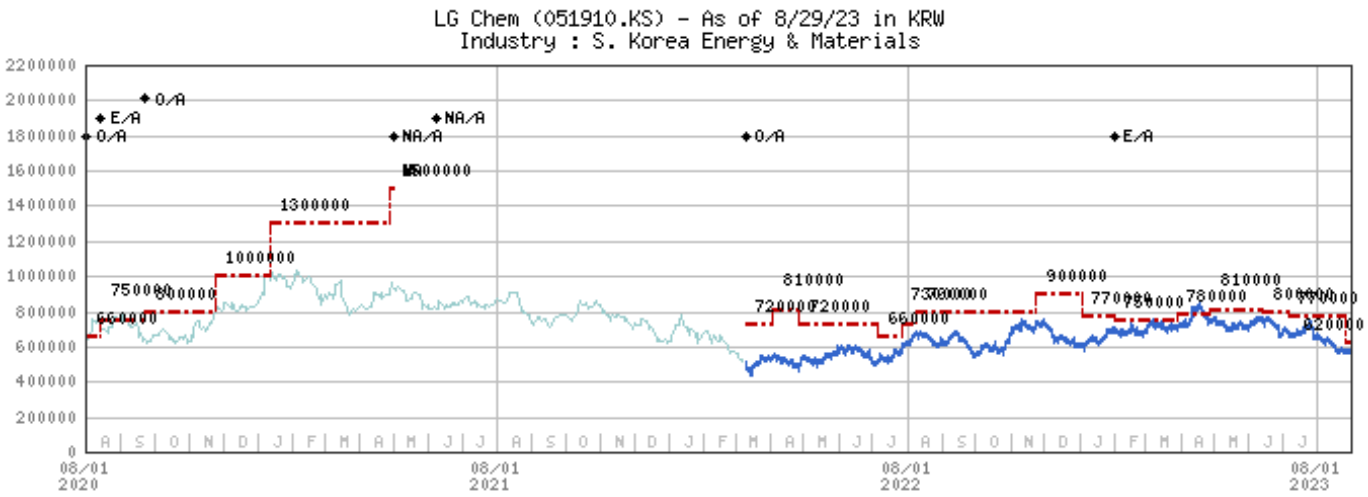
Stock and Industry Ratings (abbreviations below) appear as ◆ Stock Rating/Industry View

Stock Ratings: Overweight (O) Equal-weight (E) Underweight (U) Not-Rated (NR) No Rating Available (NA)

Industry View: Attractive (A) In-line (I) Cautious (C) No Rating (NR)

Effective January 13, 2014, the stocks covered by Morgan Stanley Asia Pacific will be rated relative to the analyst's industry (or industry team's) coverage.

Effective January 13, 2014, the industry view benchmarks for Morgan Stanley Asia Pacific are as follows: relevant MSCI country index or MSCI sub-regional index or MSCI AC Asia Pacific ex Japan Index.



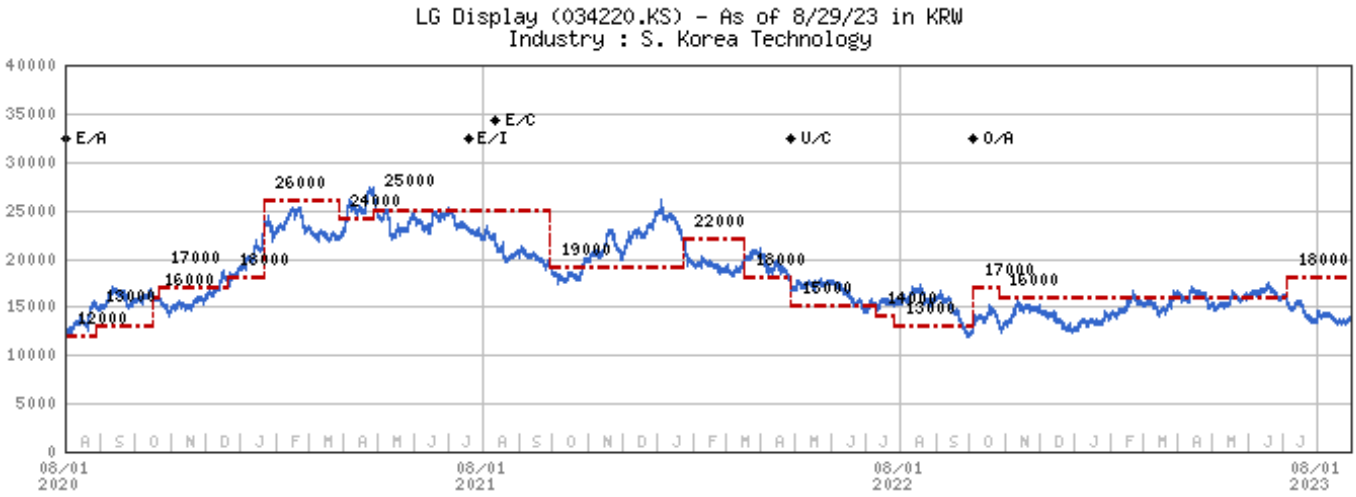
Stock Rating History: 8/1/18 : O/A; 9/13/18 : NA/A; 1/15/19 : O/A; 8/14/20 : E/A; 9/23/20 : O/A; 5/1/21 : NA/A; 6/8/21 : NA/A; 3/10/22 : O/A; 2/1/23 : E/A

Price Target History: 11/28/17 : 470000; 9/13/18 : NA; 1/15/19 : 460000; 1/30/19 : 480000; 3/12/19 : 460000; 5/28/19 : 420000; 10/3/19 : 370000; 1/17/20 : 420000; 2/19/20 : 520000; 3/18/20 : 420000; 4/7/20 : 390000; 4/28/20 : 420000; 6/9/20 : 530000; 7/8/20 : 600000; 7/31/20 : 660000; 8/14/20 : 750000; 9/23/20 : 800000; 11/24/20 : 1000000; 1/11/21 : 1300000; 4/28/21 : 1500000; 5/1/21 : NA; 3/10/22 : 720000; 4/4/22 : 810000; 4/27/22 : 720000; 7/6/22 : 660000; 7/27/22 : 730000; 8/9/22 : 790000; 11/24/22 : 900000; 1/3/23 : 770000; 2/1/23 : 750000; 3/29/23 : 780000; 4/27/23 : 810000; 6/13/23 : 800000; 7/6/23 : 770000; 8/25/23 : 620000

Source: Morgan Stanley Research Date Format : MM/DD/YY Price Target No Price Target Assigned (NA)
Stock Price (Not Covered by Current Analyst) Stock Price (Covered by Current Analyst)
Stock and Industry Ratings (abbreviations below) appear as ◆ Stock Rating/Industry View
Stock Ratings: Overweight (O) Equal-weight (E) Underweight (U) Not-Rated (NR) No Rating Available (NA)
Industry View: Attractive (A) In-line (I) Cautious (C) No Rating (NR)

Effective January 13, 2014, the stocks covered by Morgan Stanley Asia Pacific will be rated relative to the analyst's industry (or industry team's) coverage.

Effective January 13, 2014, the industry view benchmarks for Morgan Stanley Asia Pacific are as follows: relevant MSCI country index or MSCI sub-regional index or MSCI AC Asia Pacific ex Japan Index.



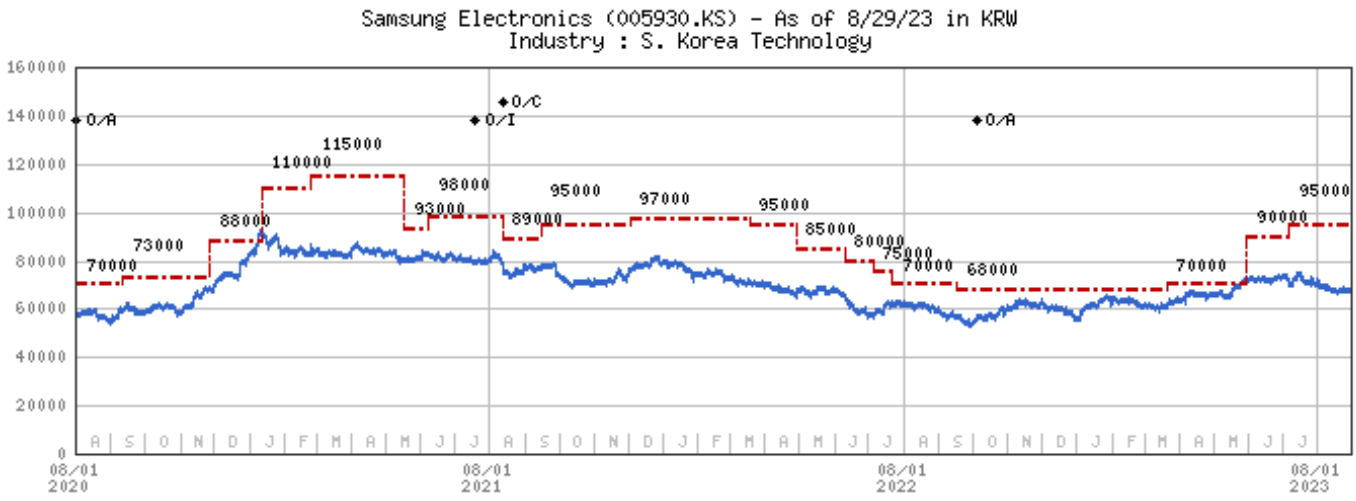
Stock Rating History: 8/1/18 : E/C; 7/30/19 : E/I; 11/18/19 : E/A; 12/9/19 : O/A; 3/19/20 : E/A; 7/19/21 : E/I; 8/12/21 : E/C; 4/27/22 : U/C; 10/4/22 : O/A

Price Target History: 7/23/18 : 22000; 10/24/18 : 20000; 1/22/19 : 19000; 7/4/19 : 18000; 7/23/19 : 17000; 8/16/19 : 14000; 12/9/19 : 19000; 3/4/20 : 17000; 3/19/20 : 11000; 7/23/20 : 12000; 8/27/20 : 13000; 10/16/20 : 16000; 10/22/20 : 17000; 12/21/20 : 18000; 1/22/21 : 26000; 3/29/21 : 24000; 4/28/21 : 25000; 9/29/21 : 19000; 1/24/22 : 22000; 3/18/22 : 18000; 4/27/22 : 15000; 7/11/22 : 14000; 7/27/22 : 13000; 10/4/22 : 17000; 10/26/22 : 16000; 7/6/23 : 18000

Source: Morgan Stanley Research Date Format : MM/DD/YY Price Target -- No Price Target Assigned (NA)
Stock Price (Not Covered by Current Analyst) Stock Price (Covered by Current Analyst)
Stock and Industry Ratings (abbreviations below) appear as ◆ Stock Rating/Industry View
Stock Ratings: Overweight (O) Equal-weight (E) Underweight (U) Not-Rated (NR) No Rating Available (NA)
Industry View: Attractive (A) In-line (I) Cautious (C) No Rating (NR)

Effective January 13, 2014, the stocks covered by Morgan Stanley Asia Pacific will be rated relative to the analyst's industry (or industry team's) coverage.

Effective January 13, 2014, the industry view benchmarks for Morgan Stanley Asia Pacific are as follows: relevant MSCI country index or MSCI sub-regional index or MSCI AC Asia Pacific ex Japan Index.



Stock Rating History: 8/1/18 : E/C; 7/30/19 : E/I; 11/18/19 : O/A; 7/19/21 : O/I; 8/12/21 : O/C; 10/4/22 : O/A

Price Target History: 6/28/18 : 54000; 11/1/18 : 50000; 11/21/18 : 47000; 12/14/18 : 42000; 1/15/19 : 40000; 7/30/19 : 53000; 8/16/19 : 48000; 9/10/19 : 50000; 11/18/19 : 60000; 1/14/20 : 72000; 2/26/20 : 75000; 3/19/20 : 68000; 4/29/20 : 65000; 7/12/20 : 70000; 9/11/20 : 73000; 11/27/20 : 88000; 1/12/21 : 110000; 2/25/21 : 115000; 5/18/21 : 93000; 6/8/21 : 98000; 8/12/21 : 89000; 9/15/21 : 95000; 12/3/21 : 97000; 3/18/22 : 95000; 4/28/22 : 85000; 6/10/22 : 80000; 7/5/22 : 75000; 7/22/22 : 70000; 9/17/22 : 68000; 3/21/23 : 70000; 5/30/23 : 90000; 7/7/23 : 95000

Source: Morgan Stanley Research Date Format : MM/DD/YY Price Target No Price Target Assigned (NA)
Stock Price (Not Covered by Current Analyst) Stock Price (Covered by Current Analyst)
Stock and Industry Ratings (abbreviations below) appear as ◆ Stock Rating/Industry View
Stock Ratings: Overweight (O) Equal-weight (E) Underweight (U) Not-Rated (NR) No Rating Available (NA)
Industry View: Attractive (A) In-line (I) Cautious (C) No Rating (NR)

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INDUSTRY COVERAGE: Greater China Technology Hardware

COMPANY (TICKER)	RATING (AS OF)	PRICE* (08/30/2023)
Andy Meng, CFA		
AAC Technologies Holdings (2018.HK)	E (08/10/2023)	HK$15.64
Accelink Technologies Co. Ltd. (002281.SZ)	U (05/12/2022)	Rmb27.85
BYD Electronics (0285.HK)	O (04/28/2023)	HK$35.40
China TransInfo Technology Co Ltd (002373.SZ)	E (07/18/2023)	Rmb12.81
Dahua Technology Co. Ltd. (002236.SZ)	U (07/18/2023)	Rmb21.43
Eoptolink Technology Inc Ltd (300502.SZ)	U (04/20/2023)	Rmb45.42
Genius Electronic Optical Co. Ltd. (3406.TW)	O (05/16/2023)	NT$383.00
Gosuncn Technology Group Co Ltd (300098.SZ)	U (11/07/2022)	Rmb3.49
HIKVision Digital Technology (002415.SZ)	O (11/02/2015)	Rmb35.45
Largan Precision (3008.TW)	O (05/16/2023)	NT$2,075.00
LianChuang Electronic Technology Co Ltd (002036.SZ)	E (05/16/2023)	Rmb9.90
OFILM Group Co Ltd (002456.SZ)	E (11/04/2021)	Rmb5.78
Q Technology (Group) Company Ltd (1478.HK)	O (01/09/2023)	HK$2.95
Quectel Wireless Solutions Co Ltd (603236.SS)	O (11/07/2022)	Rmb47.46
Shenzhen Transsion Holdings Co Ltd (688036.SS)	E (04/20/2023)	Rmb148.03
Sunny Optical (2382.HK)	O (05/16/2023)	HK$64.20
Suzhou TFC Optical Communication Co Ltd. (300394.SZ)	U (04/20/2023)	Rmb84.98
Wingtech Technology Co Ltd (600745.SS)	O (05/18/2022)	Rmb46.27
Xiaomi Corp (1810.HK)	O (04/14/2021)	HK$12.46
Yangtze Optical Fibre and Cable JSC Ltd (601869.SS)	U (10/13/2021)	Rmb32.32
Yangtze Optical Fibre and Cable JSC Ltd (6869.HK)	E (04/20/2023)	HK$11.12
Yongxin Optics Co Ltd (603297.SS)	E (11/15/2022)	Rmb88.05
YuTong Optical Technology Co Ltd (300790.SZ)	E (04/05/2022)	Rmb13.96
Zhejiang Crystal-Optech Co Ltd (002273.SZ)	O (11/15/2022)	Rmb10.52
Zhongji Innolight Co Ltd (300308.SZ)	E (12/01/2022)	Rmb116.00
ZTE Corporation (0763.HK)	O (06/20/2019)	HK$25.30
ZTE Corporation (000063.SZ)	U (07/02/2021)	Rmb35.20
Derrick Yang		
Advantech (2395.TW)	O (01/20/2021)	NT$349.50

AirTAC International (1590.TW)	E (08/04/2022)	NT$913.00
AU Optronics (2409.TW)	E (10/04/2022)	NT$17.75
BOE Technology (000725.SZ)	O (09/06/2019)	Rmb3.98
BOE Varitronix Ltd (0710.HK)	O (06/20/2023)	HK$7.63
Chroma Ate Inc. (2360.TW)	O (10/05/2021)	NT$285.50
E Ink Holdings Inc. (8069.TWO)	O (05/17/2023)	NT$182.50
Ennoconn Corporation (6414.TW)	O (01/20/2021)	NT$261.50
Ennostar Inc (3714.TW)	U (09/23/2022)	NT$45.80
GIS Holding Limited (6456.TW)	E (05/06/2023)	NT$62.40
Hiwin Technologies Corp. (2049.TW)	E (08/11/2023)	NT$200.50
Innolux (3481.TW)	O (10/04/2022)	NT$14.50
Lens Technology (300433.SZ)	E (07/22/2020)	Rmb12.18
Leyard Optoelectronic Co Ltd (300296.SZ)	E (11/03/2020)	Rmb6.27
Radiant Opto-Electronics Corporation (6176.TW)	O (12/01/2020)	NT$118.50
Sanan Optoelectronics (600703.SS)	U (08/21/2023)	Rmb15.63
TCL Corp. (000100.SZ)	E (06/11/2019)	Rmb4.06
Tianma Microelectronics (000050.SZ)	U (01/24/2018)	Rmb8.46
Visionox Technology Inc (002387.SZ)	E (02/18/2020)	Rmb8.23
Wuhan Jingce Electronic Group Co Ltd (300567.SZ)	E (11/26/2021)	Rmb86.20
Wuhu Token Science Co. Ltd. (300088.SZ)	U (06/20/2023)	Rmb5.89
Howard Kao		
Accton Technology Corporation (2345.TW)	E (11/12/2021)	NT$477.00
Acer Inc. (2353.TW)	E (05/01/2023)	NT$36.40
Asustek Computer Inc. (2357.TW)	O (08/01/2023)	NT$403.00
Compal Electronics (2324.TW)	E (05/01/2023)	NT$32.90
Flexium (6269.TW)	E (04/27/2018)	NT$89.90
Giga-Byte Technology Co. Ltd. (2376.TW)	O (12/15/2022)	NT$354.00
Gold Circuit Electronics Ltd. (2368.TW)	O (10/06/2022)	NT$208.50
Guangdong Fenghua Adv. Tech. (Hldg) Co (000636.SZ)	E (05/12/2021)	Rmb14.52
Inspur Electronic Information (000977.SZ)	E (08/28/2023)	Rmb39.54
Kinsus Interconnect Tech. (3189.TW)	U (12/21/2022)	NT$105.50
Lenovo (0992.HK)	O (05/01/2023)	HK$8.66
Lotes Co. Ltd. (3533.TW)	O (10/06/2022)	NT$881.00
Nan Ya PCB (8046.TW)	U (12/21/2022)	NT$243.00
Pegatron Corporation (4938.TW)	E (03/07/2022)	NT$78.50
Quanta Computer Inc. (2382.TW)	O (05/01/2023)	NT$248.50
Shengyi Technology Co Ltd. (600183.SS)	E (05/26/2022)	Rmb14.91
Shennan Circuits Co Ltd (002916.SZ)	E (08/24/2023)	Rmb65.89
Unimicron (3037.TW)	U (02/22/2023)	NT$184.00
Wistron Corporation (3231.TW)	O (07/12/2023)	NT$112.00
Wiwynn Corp (6669.TW)	O (07/12/2023)	NT$1,700.00
Yageo Corp. (2327.TW)	O (01/04/2022)	NT$482.50
Zhen Ding (4958.TW)	E (08/02/2022)	NT$96.80
Sharon Shih		
Asia Vital Components Co. Ltd. (3017.TW)	O (05/04/2023)	NT$335.50
Auras Technology Co Ltd (3324.TWO)	E (05/04/2023)	NT$283.50
BizLink Holding Inc (3665.TW)	O (02/20/2023)	NT$248.50
Catcher Technology (2474.TW)	U (04/23/2021)	NT$177.00
Cubic Sensor and Instrument Co Ltd (688665.SS)	E (08/18/2022)	Rmb80.71
Delta Electronics Inc. (2308.TW)	O (07/13/2017)	NT$346.50
Foxconn Industrial Internet Co. Ltd. (601138.SS)	O (07/10/2019)	Rmb21.80
Foxconn Technology (2354.TW)	E (08/16/2016)	NT$55.30
GoerTek Inc (002241.SZ)	E (12/05/2022)	Rmb15.32
Guangzhou Shiyuan Electronic Tech Co Ltd (002841.SZ)	E (10/28/2021)	Rmb53.35
Hon Hai Precision (2317.TW)	E (01/09/2023)	NT$106.00

LandMark Optoelectronics Corporation (3081.TWO)	U (04/27/2023)	NT$97.70
Lingyi Itech Guangdong Co (002600.SZ)	E (08/28/2023)	Rmb5.95
Lite-On Technology (2301.TW)	O (07/31/2023)	NT$138.50
Luxshare Precision Industry Co., Ltd. (002475.SZ)	O (10/24/2016)	Rmb32.90
SDI Corporation (2351.TW)	E (04/26/2023)	NT$101.50
Sunonwealth Electric Machine Industry Co (2421.TW)	O (08/07/2023)	NT$132.00
Tong Hsing (6271.TW)	E (03/18/2019)	NT$131.00
Visual Photonics Epitaxy Co Ltd (2455.TW)	U (04/14/2023)	NT$147.00

Stock Ratings are subject to change. Please see latest research for each company.
* Historical prices are not split adjusted.