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How Apple and Samsung have changed the display industry and what might we expect in the future, in my opinion

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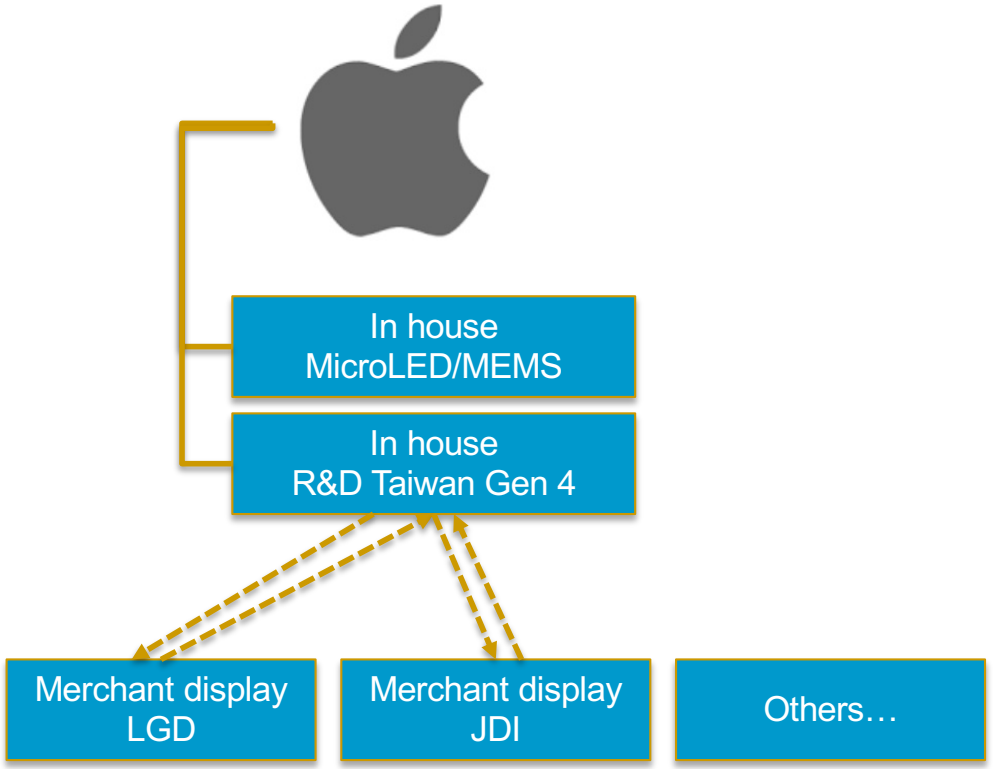
Context

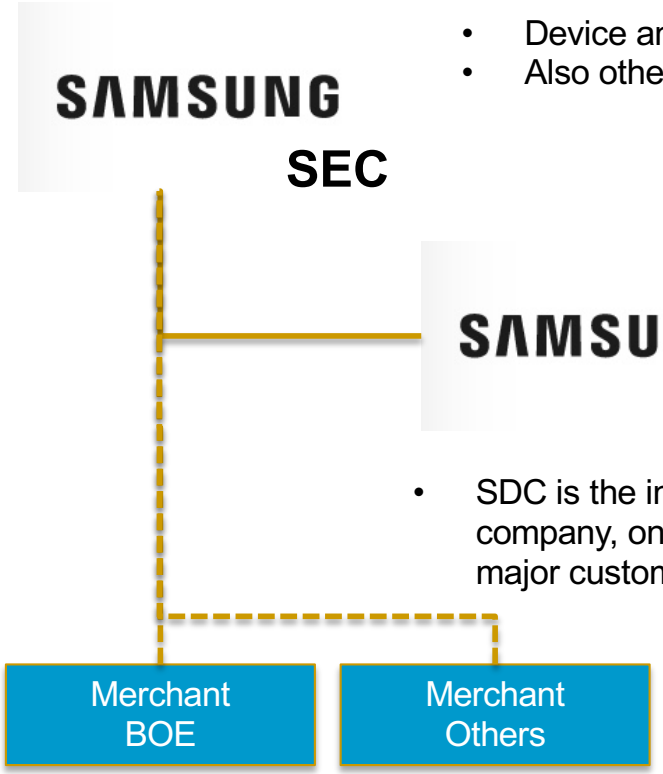
- Apple and Samsung (SDC+SEC) have both substantially influenced the development of the display industry, its products, its technologies
- This presentation seeks to look at 10+ major case examples of the level of impact that these ”two” companies have had on the display industry
- These two firms innovate in different ways
  - One is the “purist” looking for fundamental category breakthroughs or changes in industrial design that can be supported through new display technology and manages a supply chain indirectly (although becoming more actively involved)
  - The other is the “pragmatist” who operates through a mixed model of in-house capacity and outside merchant supply and whose innovations may well be to do with manufacturing process changes, the use of new materials and a more risky product trial marketing approach
- We look at the big bets and changes and then ask: What new display innovations might each find interesting in the future…
  - This is purely *our guess and speculation* but is based on having looked at what they have done in the past
- We would love your feedback – do you agree? What other axes are important to consider and which key innovations would help fill out the picture of the key moves made by these two

Source: HCL

Firstly when we say Apple and Samsung we mean different models being used:



- While having a great number of very talented people, Apple's exposure to display making directly is much more limited and has been built up over the last 5 years
- On the whole Apple manages its innovation through strategic purchase agreements, sometimes the assignment of equipment and longstanding innovation partnerships



- Device and TV assembler
- Also other businesses
- SDC is the in house display company, one of whose major customers is Apple

- Samsung's presence in displays is much more complex since it has its own very strong display division (SDC)
- Sometimes SEC and SDC pursue different strategies
- A case in point at the moment is around MicroLED vs QD OLED for the next generation of emissive large displays – SEC is pursuing Mini-MicroLED and SDC is pursuing QD OLED. We discuss the companies separately if the distinction is important throughout this deck

Source: HCL

How Apple has changed the display industry: and what may be next

Major innovations

- In cell touch*
- FFS
- (Flex) OLED Smartphone
- Higher resolution iPads IGZO
- LTPO
- Capacitive touch

Future possible interest areas

- MiniLED
- MicroLED
- AR-VR Micro displays related
- LTPO and flex OLED innovations
- New categories with unseen options

- Apple right from the iPhone has changed the shape of the display industry fundamentally
- Apple differs from Samsung in both its value chain approach but also that focuses on devices (and does not have a TV level play)
- It has been rumoured for quite a while that Apple has an interest in MicroLED after its acquisition of LuxVue. Apple Glass(es) have also been long discussed in the blogs. We wonder whether Apple will extend their innovations similar to LTPO and then simplications in general in the flex OLED space

* SDC actually put out in-cell touch first based on work from Planar Systems sold to them, but Apple drove the volumes

Source: HCL

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How Samsung has changed the display industry and ”So what next”. More display centric/Pragmatic

Major innovations

- OLED (Unusual primaries)
- FMM deposition
- QD OLED and QD innovations
- Phablets and stylus equipped phones
- Y-OCTA and TOE
- Functional integration (FOD/HOD/SOD)
- MicroLED “The wall”
- 8K

Future possible interest areas

- MiniLED
- MicroLED
- More innovations in colour space
- Galaxy Fold etc
- Functional integration
- QD EL and other QD innovations

- Samsung also has provided some major innovations to the display industry
- Its orientation is more pragmatic – focusing on functional integration, an interest in inorganic material systems, colour and manufacturing approaches
- Expect more of the same and emphasis on foldable

Source: HCL

Case studies (1) : How the first iPhone changed the display industry

Major innovation	Implication	Beneficiaries
PCAP	• Apple single handedly redefined the GUI and display expectations and created the Smartphone category • It also gave massive impetus to the capacitive touch industry	• Companies like TPK, Nissha and others who have built up a > $10bn business in total • The touch industry has had a fluctuating relationship regarding full integration into the display vs separate piece parts
Large transmissive TFT Display	• Prior to the iPhone, phone displays had been much smaller MSTN, CSTN or transflective a-Si TFT designs • Apple's move put huge weight on the role of transmissive TFT	• Sharp and others making transmissive smartphone displays • The Smartphone display category is now worth more than $40bn

Source: HCL, Apple (Image)

Case studies (2) : How the recent iPhones also have changed the industry building on the start from Samsung. Note that SDC did much of the display level heavy lifting

Major innovation	Details and Implication	Beneficiaries

Flex OLED	• The move to flexible OLED brought with it several major innovations in production equipment and materials
	  • Spun PI processing
	  • New plastic substrate materials
	  • TFE (See later)
	  • Laser lift off processing
	• It also started down the trend towards “full face” displays with notches or holes
		• These innovations created completely new equipment and materials applications to support this
		• The beneficiaries include substrate providers (e.g. Ube Kosan, KOLON), TFE equipment players (Kateeva, AMAT), lift off players (AP Systems) and others

Source: HCL, Samsung Apple images

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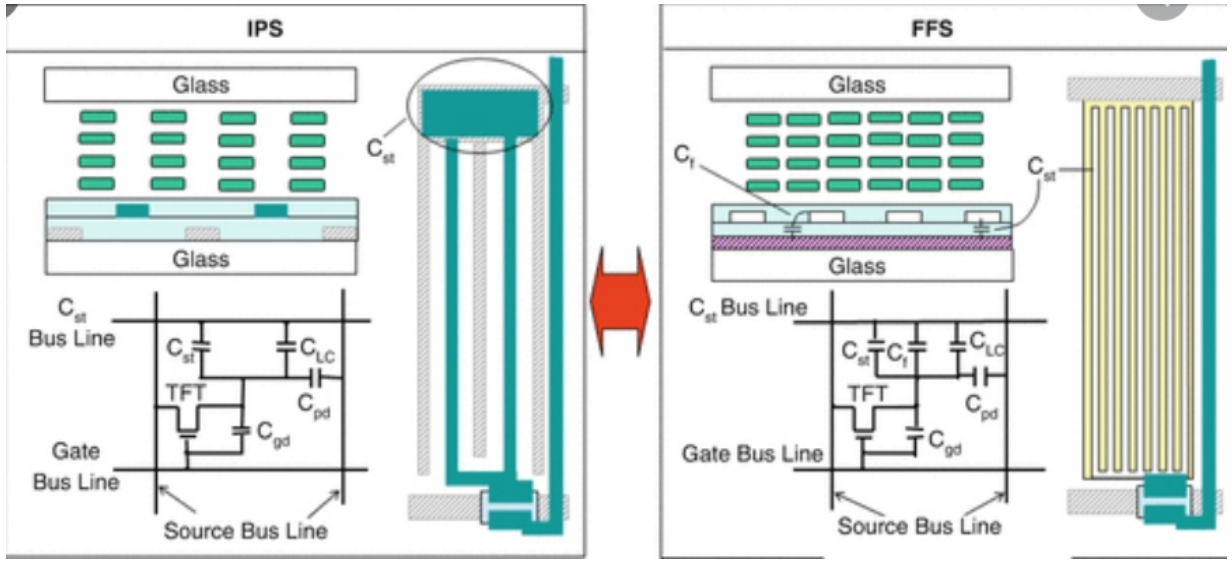
Case studies (3) : How FFS from Apple changed IPS adoption



Details and Implication

- Apple decided to implement the FFS (Fringing Field) IPS approach across its product range for its lower power, slightly better viewing angle and speed
- This was a TFT device design pioneered by Hydis in Korea and then acquired by EIH
- FFS pixel designs are now found from quite a number of display majors

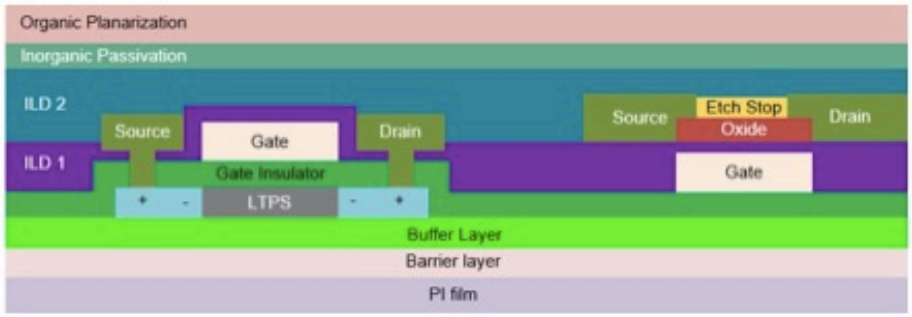
Beneficiaries

- EIH has made a robust royalty line collecting from many of the major display players (including LGD) for this technology
- The difficulty of this is for a company to try the same strategy again – not clear which patents or approaches will necessarily be seized by Apple and hence become golden eggs for their owners

Source: HCL

Case studies (4) : How LTPO from Apple changes the old industry conventions on power consumption

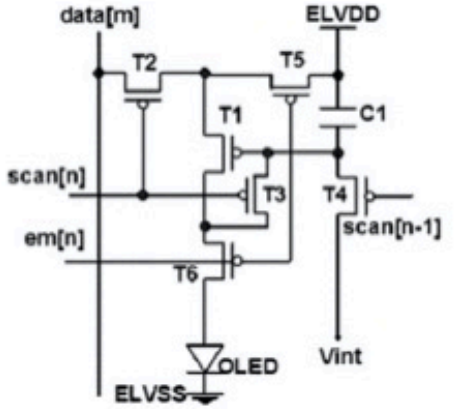
LTPO backplane only cross section and 6T1C pixel schematic example



Benefits:
- Reduced power consumption (10%+)
- Narrow border with integrated gate drivers
- DeMuxed source drivers
- Improved uniformity
- High resolution

Challenges:
- Increased layers and photo steps (+20-40%)
- Increased costs
- Decreased yields

Opportunities:
- Expand to iPhone and other applications
- Reduced mask count by process step integration



Note: These are current assumptions only of one of multiple potential LTPO pixel layouts assuming oxide driving TFT. Not based on tear down analysis or intended to represent any currently commercialized products.
Source: IHS Markit assumptions for cross section, pixel schematic example source unknown

Description and Implication of this technology move

- On the whole the display industry prioritizes cost and brightness over power consumption – the mantra in the device market over the last years has pretty much been one of larger batteries and asking consumers to adopt behaviours to charge their phones. Bistables to exist in the display world but to a much smaller degree
- This changes with Apple's move to LTPO which combines both LTPS with Oxide to gain a 15% power saving

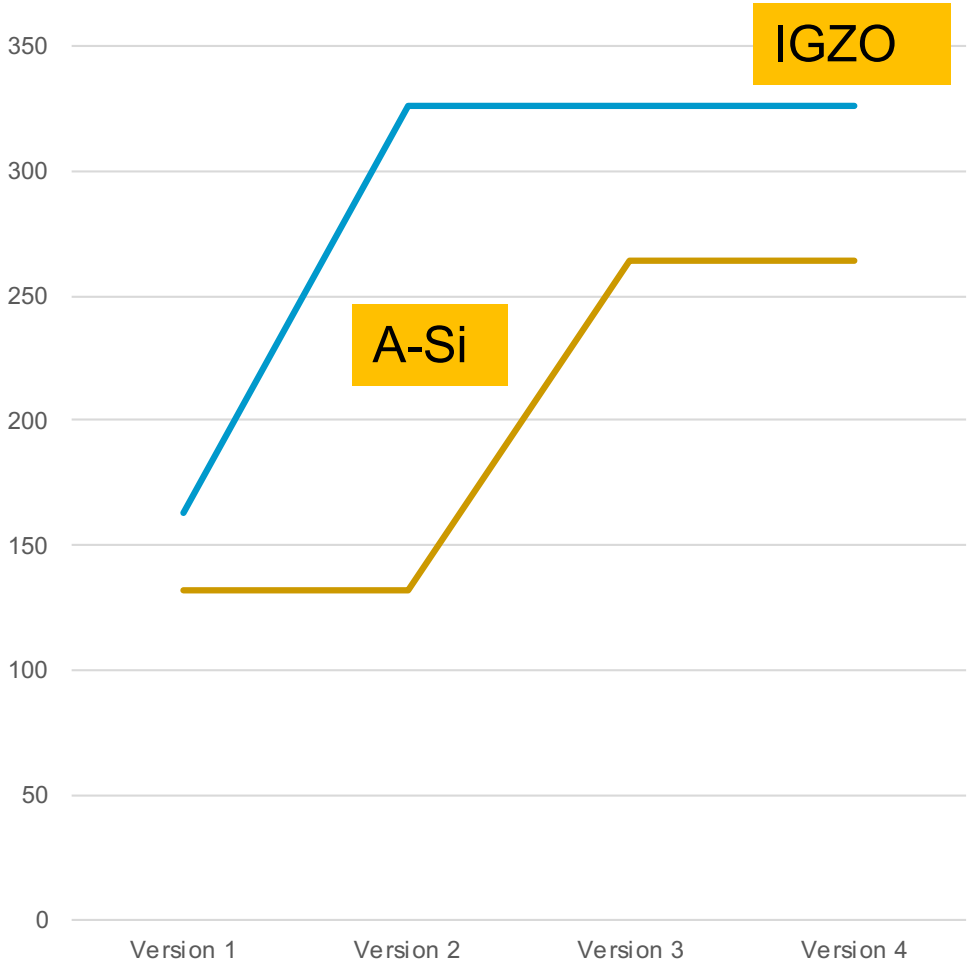
Beneficiaries

- The patent for this is Apple's
- The major beneficiary of this to be honest is the equipment industry based on the additional number of masks in the LTPS stack – in particularly the litho players (especially Nikon) may do well out of this innovation

Source: HCL, OMDIA

Case studies (5) : IGZO resulting from higher resolution iPads

DPI of Ipad and Ipad Mini



Implication

- The main iPad pro and early version full size iPads were based on IPS (FFS) a-Si
- That changed with the Ipad mini, where Apple's strategy of pixel doubling took the resolution of the display up into IGZO territory

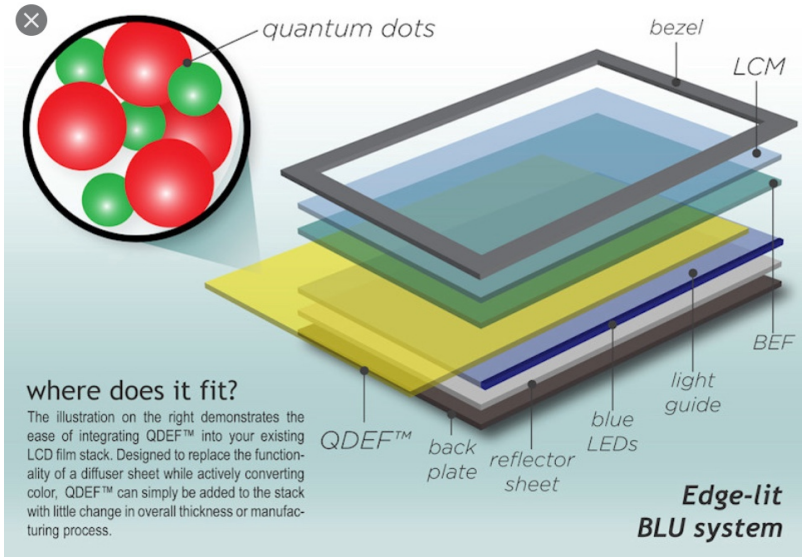
Beneficiaries

- The beneficiaries of the IGZO move benefitted those display players with IGZO capability (e.g. Sharp)

Source: HCL analysis

Case studies (6) : How Samsung has changed colour-space with the use of QDs

QDEF (QLED)



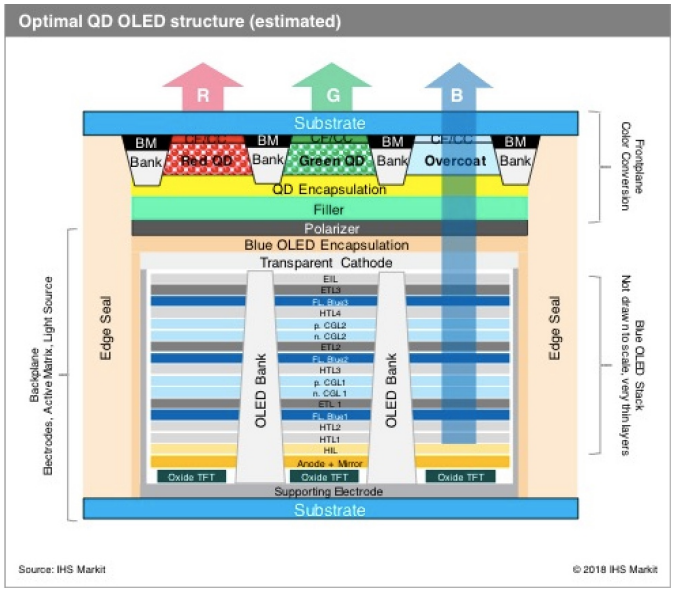
Details and Implications

- Samsung (SEC) was the lead sponsor of work on QDEF films. Now >6m m^2 and growing

Beneficiaries

- Nanosys and its range of film partners
- Hansol
- Najing Tech

QD OLED



Details and Implication

- The use of QDs as a colour conversion layer in QD OLED based on fluorescent blue emitters (SDC)

Beneficiaries

- The beneficiaries here will be the equipment companies – and especially Tokki, SEMES and perhaps Kateeva and AMAT

Source: HCL, 3M Image, OMDIA

Case studies (7) : How Samsung has suggested a completely new innovation lever in foldables. Apple may simply choose not to follow here – their fascination is on how devices work in the hand

Details and Implications

- SDC worked on a >5 year agenda to deliver different levels and flexible and foldable device performance culminating with the Galaxy Fold (as shown)
- This (similar the discussion of the Iphone X) involved processes like spun PI, laser lift off, flex device planes) but also a number of more sophisticated problems such as thinner simpler stacks, changes to device design and new materials

Beneficiaries

- The beneficiaries of the work on foldables include those that benefitted from flex OLED but then additionally:
  - Thin glass players seem to have won out compared to the use of plastic substrates (e.g. Schott)
  - Thinner polarization films, thinner layers of OCA: e.g. Nitto Denko and Sumitomo Chemical
  - Thin Colorless PI from Kolon

Source: HCL, Samsung (Image)

Case studies (8) : How Samsung developed FMM and TFE
Two key processes needed for top emission OLED

FMM

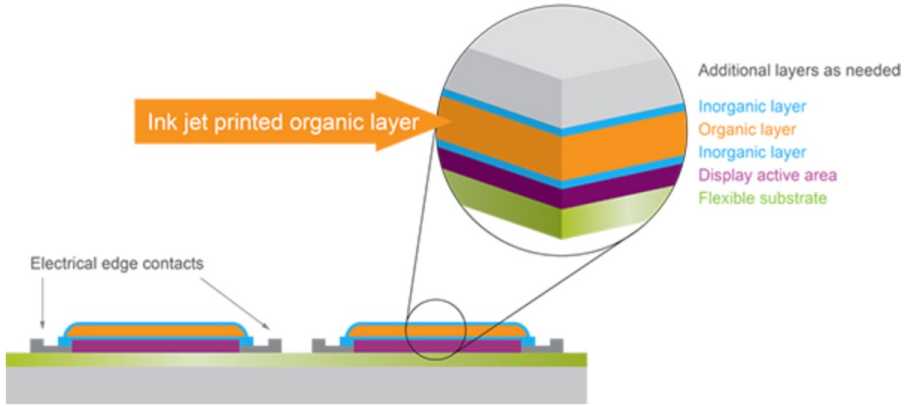
Details and Implication

- The FMM process was developed by Samsung and Tokki (and others) and was one of the key breakthroughs that allowed mass OLED making

Beneficiaries

- Tokki, ULVAC and others
- Tokki remains dominant overall with some tools at rumouredly very high prices ($400m)

TFE



Details and Implication

- The TFE process was one of the key innovations also on the path to top emitting flex OLEDs

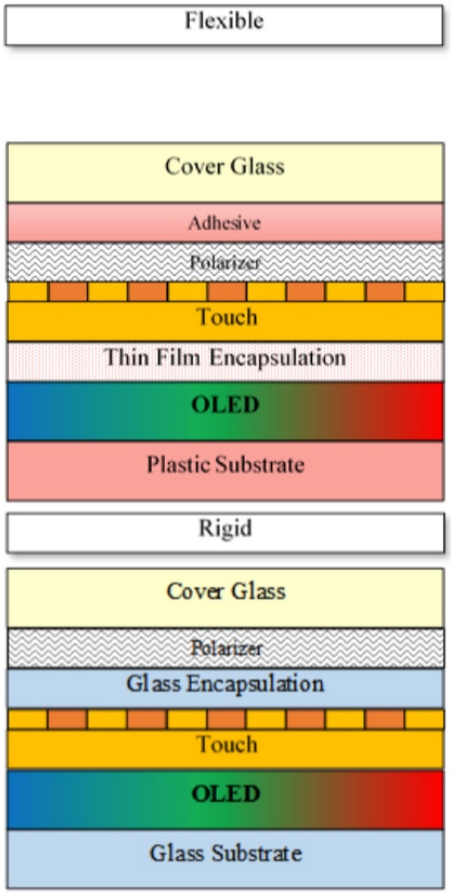
Beneficiaries

- Kateeva and AMAT the equipment companies
- SDI supplies the monomers

Source: HCL, Tokki, Kateeva

Case studies (9) : How Samsung innovated with Y-OCTA, and FOD/HOD/SOD

Y-OCTA



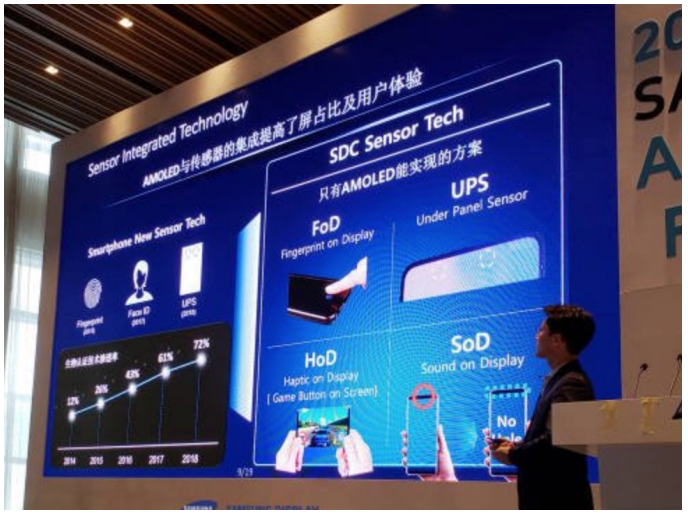
Details and Implication

- Y-OCTA is the SDC approach to integrated touch for Smartphone using an overall smaller number of layers where the touch panel is created directly on the top encapsulation layer

Beneficiaries

- Again the litho tool companies seem to be the net beneficiaries here of this innovation

Functional integration FOD/HOD/SOD



Details and Implication

- SDC has now started on the aim of integrating further functions within the LTPS of their AMOLEDs

Beneficiaries

- The aim here is for themselves to be the biggest beneficiary of integrating fingerprint sensing (FOD), Haptics (HOD) or Sound (SOD)

Source: HCL, Samsung (Image)

Case studies (10) : How Samsung may change the industry again with Mini-MicroLED “The Wall”

Details Implication	Beneficiaries
• Samsung Electronics work on MicroLED includes a demonstrator of the technology called ”The Wall” aimed at signage and potentially high end consumer TV • Based on Mini-MicroLED concept that was first actually shown by Sony (CLEDIS)	• The beneficiaries in the short term may be LED suppliers and Kyocera who rumouredly supply LTPS tiles to Samsung for this technology

Source: HCL Marketer International (Image)

And so what next: New frontiers with some overlapping interest

Apple

Samsung

- Obsession with industrial design and GUI and user experience
- “Retina” and human factors orientation
- **Purist** orientation with respect to colour primaries
- Not the highest resolution… “Retina”
- Innovates to form new categories
- New found interest in contrast and dynamic range (MiniLED)
- New found interest in power management (LTPO)

- Interest in colour
- Interest in display technology driven innovations
- Pragmatic
- Innovators in colour and resolution but to levels “beyond human acuity” and Innovators in form factor (Phablets, foldables)
- Bright and bold
- ”Pizzazz”, specification-based marketing

- LTPO and flex OLED simplification
- MicroLED and MiniLED
- AR-VR and micro displays
- New categories enabled by new display types

- MicroLED and MiniLED may end up being of interest to both

- QD related innovation
- Captive supply in Korea
- AR-VR topics but delivered mainly for now by SmartPhone and headset

Source: HCL

…and who benefits:

Apple

Samsung

- FFS: EIH
- (Flex) OLED: SDC, LGD, BOE
- LTPS LCD: JDI and others
- IGZO LCD: Sharp
- MiniLED and MicroLED: Unnamed LED suppliers
- Apple using its own IP
- PCAP touch: Nissha, TPK, others

- Y-OCTA: Litho players (Nikon)
- QD OLED/QD in general/QDEL: Nanosys, Hansol, Nanophotonica
- Functional integration: SDC themselves
- FMM and TFE: Tokki, Kateeva, AMAT
- OLED materials: UDC, Merck, others

- The winners are more globally distributed
- Apple places supply and acquires small companies
- Apple creates ecosystems that then may flourish thereafter

- The winners are more likely to be Korean but there are some Japanese and US based materials and equipment companies in this list
- Samsung creates **tightly controlled** ecosystems if they can

Source: HCL, other guesses

So what ends up next and who benefits:

MicroLED

AR-VR Micro displays related

LTPO and flex OLED innovations

New categories with unseen options

MiniLED

LGD, SDC, Litho players, (Micro+ Mini) LED players, optics and micro displays players, EIH, AMAT, Kateeva and owners of novel technology (like LuxVue)

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MiniLED

MicroLED

More innovations in colour space

Galaxy Fold etc

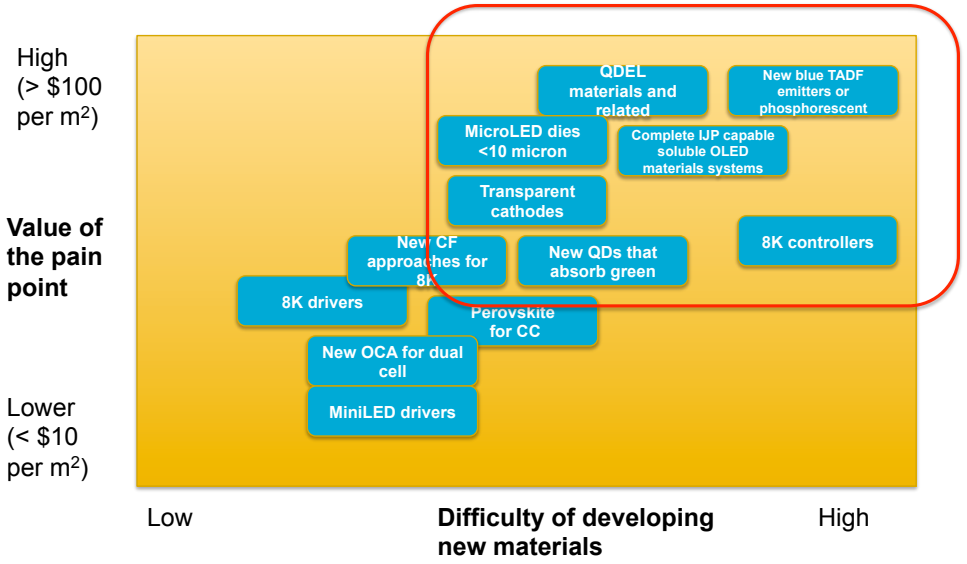
Functional integration

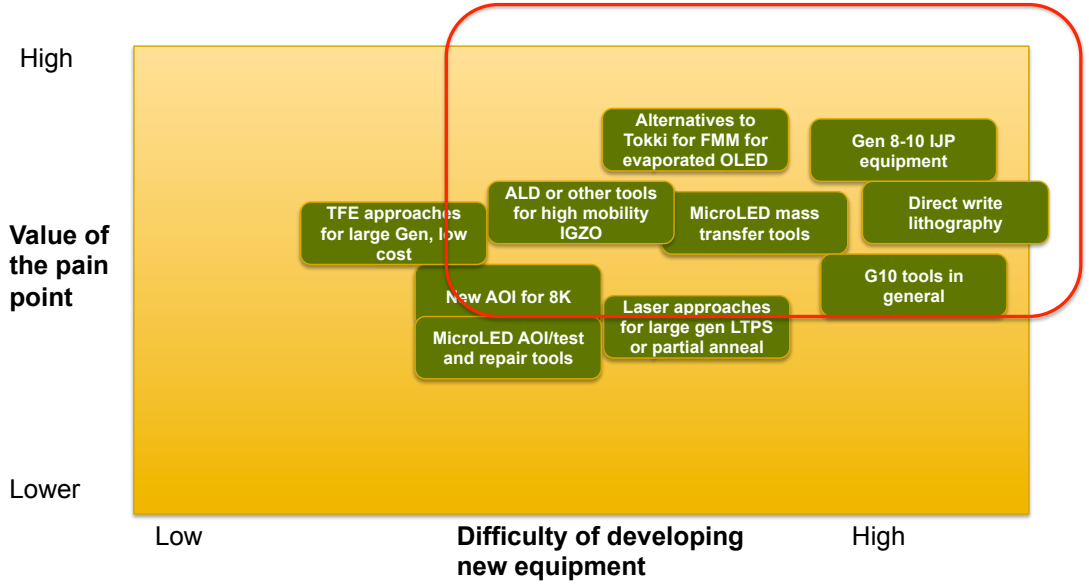
QD EL and other QD innovations

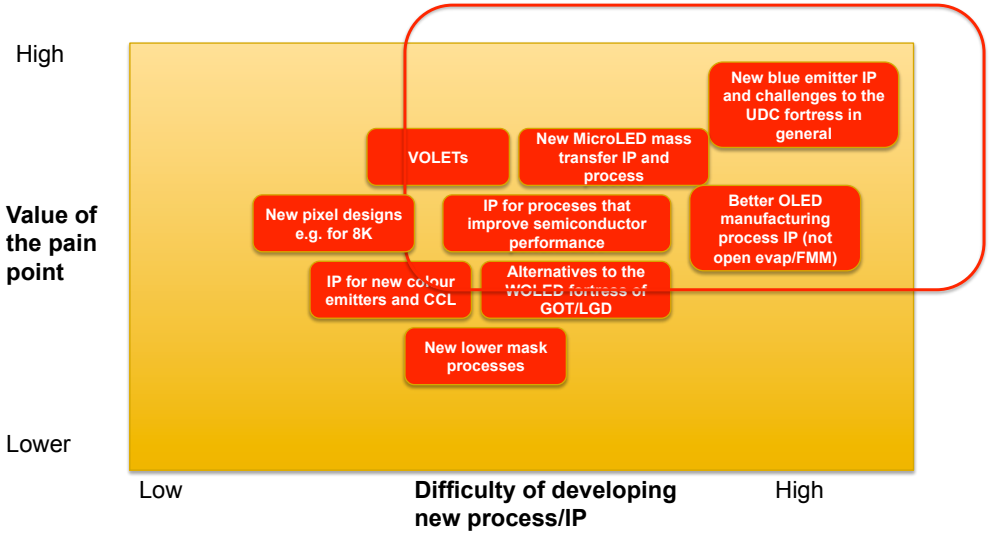
Nanosys, Hansol, Nanophotonica, Sumitomo Chem, KOLON, Nitto Denko, SDC themselves and the Micro/Mini LED players plus equipment companies: AMAT, APS, Kateeva, Tokki

Source: HCL

One of my previous presentations was on the sources of innovation I could see from the current innovation in TV:



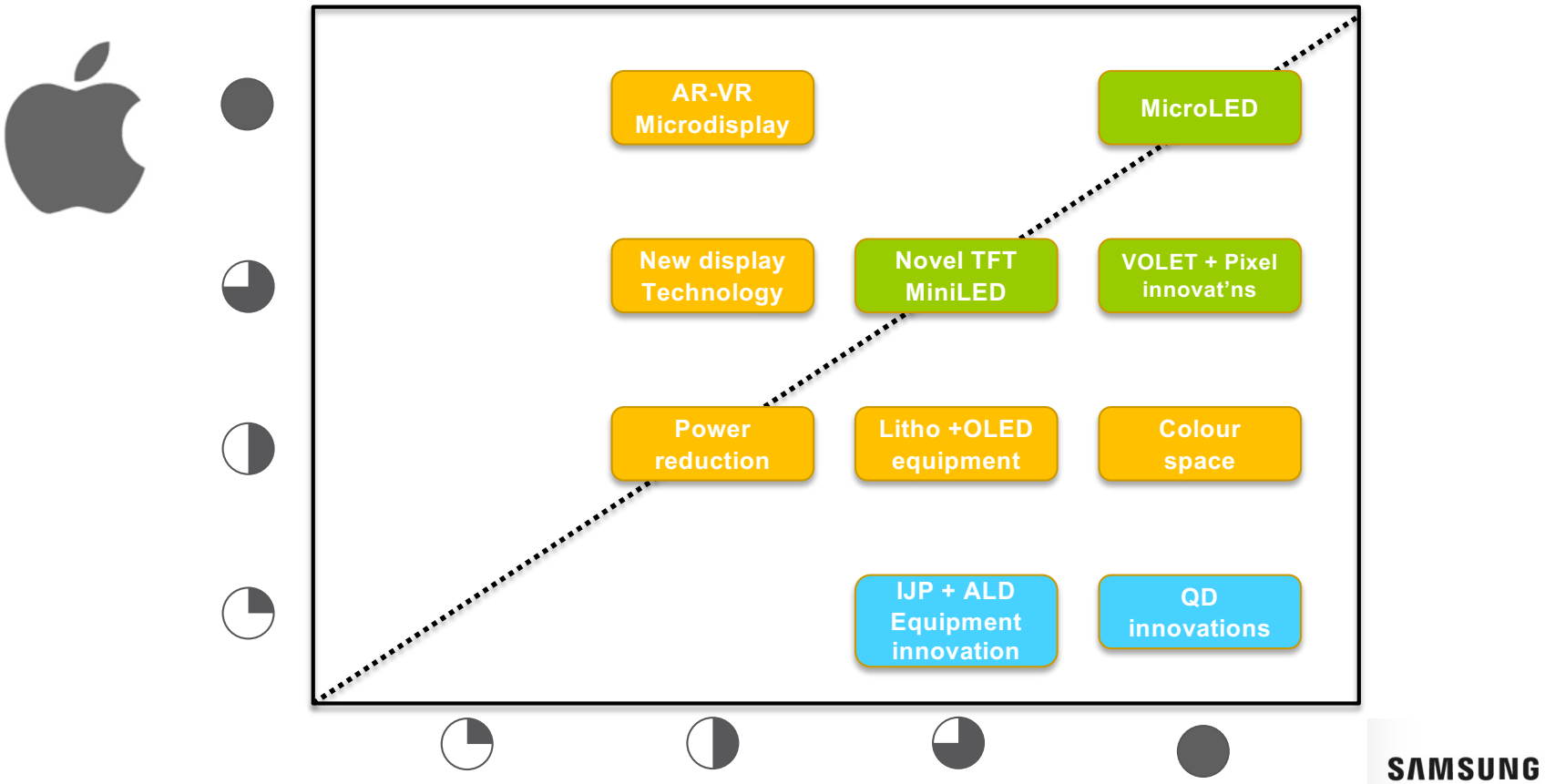




- Quite a few business opportunities for the display value chain to work on
- Innovation creates new options

Source: HCL

But their design philosophies and choices for key innovations are very different, so their **level of interest** may be different in future areas of innovation: **Our brainstorm and our thoughts.** Do you agree?



Source: HCL

My best **guesses** of the level of interest from each company into a number of display level innovations: What do you think?

		SAMSUNG
QDEL	◔	●
Blue emitters	◑	●
Soluble IJP/IJP general	◔	◕
MicroLED	●	●
QD innovations	◔	●
Perovskites	◔	●
VOLETs	◕	●
Novel TFT designs	◕	◕
AR-VR through Microdisplays	●	◑

		SAMSUNG
Colour space related innovation	◑	●
ALD	◔	◕
Litho equipment innovation	◑	◕
OLED equipment improvements	◑	◕
New emitters	◑	●
New display technologies	◕	◑
Power reduction technology	◑	◑
Pixel related innovation	◕	●
MiniLED	◕	◕

More interest ● ◕ ◑ ◔ Less interest

Source: HCL

Summary and implications

- Apple and Samsung have both created immense impact on the display industry
- However, they are the “purist” and the ”pragmatist” with very different emphases in terms of areas of interest and due to their differing business models
- This presentation seeks to look at 10+ case examples and try to show the impact of the innovations on the direction of the total industry
  - We also then try to draw out implicitly key themes and distinctions on motivations

- We try to look at future innovations and offer our own suggestion of which areas of technology may be of more interest to one or the other
  - Now this is purely our own guess, but we would love your feedback. We know that both probably have teams looking across the whole spectrum of innovations, but only certain ones get emphasized in new products and new fabs

- One of the interesting conclusions is that Mini + MicroLEDs are of potential interest to both and we wonder what the impact of this may be: A bidding war and effort to secure appropriate supply/partners? Both may be fundamentally interested in pixel innovations too – in terms of LTPO or other custom stacks to give functional benefits

Source: HCL

Our services:

Growth strategy	Performance improvement	Equipment and Capex	Sourcing strategy (Purchasing)
• Market entry strategy • Business unit strategy • Growth strategies for new technologies	• Product portfolio management • Pricing strategy • Cost reduction	• LCD/OLED factory capex decisions • Strategies for equipment makers	• Sourcing strategies, especially LCD and medical detectors • Make/buy decisions

Technology strategy and technology assessment	Partnering and alliances	Professional advisory and business planning	Strategies for materials providers
• Market and commercial strategies for new technology businesses • Market tracking services for corporates monitoring technology	• M&A candidates and assessments • Alliance formation support • Post merger integration planning	• Specialist insights for bankers, equity investors and other consultancies • Reviews of business plans and models (Strategic audits)	• Strategy support for materials providers in the FPD, SSL, and PV markets • IP and pricing plans

Source: HCL

Projects recently completed:

By display technology

- MicroLED
- OLET
- IJP
- Novel lithography
- OTFT
- Reflective displays
- OLED
- ALD
- Novel transistor design
- QD-Perovskites
- TFE
- Novel semiconductors

By assignment type

- Market entry
- Growth strategy
- Business plan validation
- Executive workshops
- Portfolio review
- Marketing plans
- Value based decision making
- Equipment and materials strategy
- Customer interviews
- Investment committee support
- Cost analysis
- Display fab modeling
- IPO preparation
- Competitive and market intelligence

Source: HCL