Status Of the Sapphire Industry.

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Senior Analyst – LED, Sapphire and displays.
FIELDS OF EXPERTISE

Yole Développement’s 30 analysts operate in the following areas:

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- MEMS & Sensors
- Compound Semi - LED
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There's more than just LEDs!

2015 Material Consumption Breakdown Per Applications.
(Note: excludes traditional watches, aerospace, defense, medical, industrial etc…)
Dramatic global excess capacity!

But situation is complex:

- Leaders still operating at close to full capacity while tier-2 are idle.
- Large amount of capacity is not qualified for most applications.
- “Ghost Capacity” in China

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1. Includes: LED, optical wafers, SOS, Apple Watch.
2. Supply and demand for LED, Optical wafers and SOS (excludes Apple Watch finishing capacity at Biel and Lens which requires 2.5D and 3D capabilities)
3. Open market only: excludes demand and capacity at LED makers
WHY CAPACITY IS SO HIGH AND KEEPS INCREASING?

Anticipation of fast growing LED applications:
10’s of new entrants all setting up capacity to become #1 !!!

Leaders with high Utilization Rates:
Monocrystal  
Aurora / 奥瑞德  
...

Vertical Integration:
Biel-Roshow / 伯恩露笑蓝宝石  
Lens / 藍思科技  
San’an / 三安光电  
HC Semitek / 华灿光电…

Duplication of capacity!

Anticipation of new applications (Display covers) + More subsidies (Inner Mongolia)
DARX / 达瑞祥光电科技  
EGing / 亿晶光电科技  
Kingsun / 内蒙古鑫晟光电科技有限公司  
Biel-Roshow / 伯恩露笑蓝宝石  
Lens / 藍思科技  
Aurora / 奥瑞德 …
• Strong incentive to increase capacity even if there is no market.
• GDP growth through investment and production rather than consumption.
• In China, a company (almost) never dies!

Dumping production (boules) on the grey market for zero profit
IMPACT ON PRICES

• Excess capacity
• Total market increasing moderately but open market decreased in 2015: Vertical integration >30% of wafer market is now captive

Dramatic Price Decrease!

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Some companies resist. Others are tumbling.

- CAT victim of BIEL + LENS vertical integration of CE wafers.
- PSS focus pays off (for now).
- Russia and Japan-based companies benefit from exchange rate.
- Cost control, performance, quality…
TOO MANY PLAYERS \(\rightarrow\) RATIONALIZATION IS REQUIRED

Q1-2016 Status

~ OK (Revenue)

Strong focus on non-LED / non wafer applications

Even cost leaders currently operating below cash cost
\(\rightarrow\) strong balance sheet (or access to capital) required to survive in the storm.

Some vertical integration possible:

- Finishing + PSS ?
- Material-only business model not sustainable.
- LED makers: HC-Semitek + Crystaland.

Danger!

Gone!

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Sapphire Applications Trends
SAPPHIRE FOR LED:

Oversupply and strong inventory in H2-2015 now improving.

Strong growth in general lighting:
Massive adoption + upgrade cycle from smart lighting.

Moderate decrease in large displays:
4K, High Dynamic Range, Wide Color Gamut need more LED per TV + OLED TV delay → slow down the decline.

Strong decline in small displays: OLED
Sapphire is not a strong differentiator.

But cost is decreasing:
Now < US$0.50

→ Accelerate adoption?
Dual Camera:
Improves depth of perception, brightness, low light and color performance.
DUAL CAMERA IPHONE 7 COULD INCREASE SAPPHIRE USAGE

Previous iPhones:
Circular lens covers extracted from 2” wafers

20 cm² - 52 lenses

iPhone 7 ???
Oblong lenses from larger square wafers (?)

36 cm² - 28 lenses

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The Meizu MX4 Pro (魅族):
Fingerprint reader from Goodix with a sapphire cover

• New entry level 4” “iPhone SE”
• Fingerprint readers will become as popular as camera phones.

• Sapphire is expensive (~$1.9)
• New high-k material are emerging.
• Apple has strong IP → very low adoption outside Apple

All iPhone and most iPad now have fingerprint readers
WILL APPLE (AND OTHERS) ELIMINATE THE HOME BUTTON?

2015

Button for fingerprint sensor

2017 – 2018?

Fingerprint sensor is under the display or into the display stack
SMARTWATCH: VERY DISAPPOINTING (SO FAR…)

- Only ~10% of Apple Watches sold featured a Sapphire display cover?

- Only other major brand using sapphire: Huawei

- But sapphire strong with high low/volume high margin models from the Swiss Industry (Tissot, TAG Heuer…)

- Will new Apple Watch stimulate the market and offer strong use case?

2015 Smartwatch Shipments

- **Apple**: 1.5m Units
- **Huawei**: 300k units
- **Others**: 22m Units

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OTHER APPLICATIONS?

- Smartphone Display
- Covers
- Lens / FPR Covers
- Defense & Aero.
- P.O.S
- Others

Barriers to Entry
- Low
- High

Bubble size represents potential 2018 revenue

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Will New Applications Emerge?
Cover Glass or No Cover Glass???
Drivers for adoption

- Superior scratch resistance
- Dielectric constant?
- Prestige, appeal
- Differentiation

Uncertain Factors

- Breakage resistance
- Weight
- Reflectance
- Unknown attributes

Potential Stoppers

- Higher cost
- Manufacturability
- Environmental footprint
- Supply chain
APPLE 2013-2014: TENTATIVE SUPPLY CHAIN FOR > 40 M UNITS / YEAR

Total Investment > US$1.5 billion. Expected to operate at capacity from June 2014
APPLE 2013-2014: NO SAPPHIRE IN IPHONE 6!

Crystal Growth  | “Bricking”  | Slicing  | Shaping  | Finishing | Coating

GT ADVANCED TECHNOLOGIES

2,138 furnaces
262 kg boules

LENS TECHNOLOGY

Biel Crystal Manufactory Limited

- 180+ Multi Wire Saws
- 1000’s of lapping, grinding, polishing tools
- 100+ Laser cutting tools
- …

Supply chain, technology & Apple not ready: too early; too fast, too much…
→ GTAT Bankruptcy!

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APPLE STRATEGIC MOVE TO BROADER PRODUCT OFFERING?

Saturation of historic iPhone segment → Extension to entry level since 2013

Extend to “Pro” in 2016 and “prestige” categories in 2017?
HIGH END IPHONE WOULD BE GOOD CANDIDATE FOR SAPPHIRE

• Sapphire anchors the product into the “High end / Prestigious” phone category.

• Low volume → easier on the sapphire supply chain.

• High margin product → better tolerance to high sapphire cost.

2017 Premium iPhone With Sapphire Display Cover?

Or curved OLED with 3D glass?

Wait for more signals in the supply chain through 2016 but little hope overall for sapphire.
Potentially Emerging Applications
Increasing display requirements for mobile devices:

- Low power consumption
- High dynamic range
- Wider color gamut
- Fast response time
- Wider viewing angles
- Low cost
- High pixel density (Pixel Per Inch) for VR and AR
- Complex optic for AR

<table>
<thead>
<tr>
<th>100 PPI</th>
<th>200 PPI</th>
<th>600 PPI</th>
<th>2000 PPI</th>
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<tbody>
<tr>
<td>4K TV (&lt;100 ppi)</td>
<td>Smartphone: 200 to 600 ppi</td>
<td>Near Eye Displays: VR, AR… &gt; 2000 PPI</td>
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POSSIBLE APPLICATIONS IN DISPLAYS AND AR/VR?

- Complex optics and micro-optics in Augmented Reality applications (e.g.: substrate for grating structures)
- Substrate for high mobility TFT backplane to drive high pixel density microdisplays
- Sapphire as a substrate for GaN µLED
MICROLED DISPLAYS

Each pixel is an LED chip (~ 10 µm or less area and pitch).

Benefits:

- High brightness
- Low power consumption
- High Dynamic Range (contrast)
- Wide color gamut
- Curved / flexible backplanes
- Lifetime
- Resolution / Pixel density

Challenges:

- Pixel “pick and place”: position accuracy, throughput, cost…
- Interconnects
- Chip driving (GaN, InGaAlP)
- Low green LED efficiency

Ostendo Microdisplay: 5000 PPI
(picture: Information Display)

Illustration: VerLASE
MICRODISPLAYS, AR & VR

- Use case for sapphire still need to be demonstrated!
- But potential for new high volume consumer applications.

- Apple acquired MicroLED display Startup Luxvue.
- Magic Leap valued at > US$4.5b
- Facebook US$2b acquisition of Occulus.
- …
CONCLUSIONS

- Sapphire industry in crisis.
- LED to remain the single largest application in foreseeable future.
- Market for fingerprint + camera lens covers now mostly captive (Biel + Lens).
- Long term prospect for fingerprint cover is uncertain.
- Little hope left for display covers: niche only.
- Many sapphire companies disappearing. To survive:
  - Best cost position (yields, product mix, energy…)
  - Vertical integration or focus on PSS?
  - Recognized quality and consistency + service.
  - Strong balance sheet / access to capital to operate below cash cost until market is rationalized.
- More applications could emerge: Virtual Reality / Augmented Reality applications.
Submit your abstract!

2nd International Forum

SAPPHIRE MARKET AND TECHNOLOGIES

SHENZHEN, CHINA

SEPT. 6-7, 2016

Alongside China International Optoelectronic Expo

THANK YOU!

謝謝

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