Epitaxy Growth Equipment for More Than Moore Devices Technology and Market Trends 2020

Market and Technology Report
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  - Epitaxial growth requirements
  - Structure, thickness, cycle time
  - Type of epitaxy integrated
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  - Epitaxy drivers and challenges
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  - Epitaxial growth requirements
  - Structure, thickness, cycle time
  - Type of epitaxy integrated
  - Substrate/layers types
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Amandine PIZZAGALLI

Amandine Pizzagalli oversees the equipment and materials fields for the Advanced Packaging and Manufacturing team at Yole Développement. She graduated as an engineer in Electronics, specializing in semiconductors and nanoelectronic technologies. Prior to Yole, Amandine worked for Air Liquide, with an emphasis on CVD and ALD processes for semiconductor applications. Amandine holds an international MBA from IAE Lyon, School of Management (France) and an electronic engineering master degree from the engineering school, CPE Lyon (France) with an added degree, focusing on semiconductor manufacturing technology, from KTH Royal Institute of Technology (Sweden).

Contact: pizzagalli@yole.fr
OBJECTIVES OF THE REPORT

• This report aims to give an in-depth understanding of epitaxy growth technology, current status and prospects, roadblocks and key suppliers / players

Provide detailed information on which applications epitaxy growth technology could address in the semiconductor field

• Comprehensive analysis of the major applications currently using epitaxy growth methods, and potential/attractive applications that could require the use of epitaxy growth technology in the future
• How disruptive epitaxy technology is for established and emerging applications
• Discuss technology processes, specifications and value chain
• Epitaxy growth process applications roadmap

Describe the key benefits and added-value of epitaxy growth technology in the semiconductor field

Present the current status of epitaxy growth technologies

• What are the remaining roadblocks?
• Discuss the remaining challenges facing epitaxy growth technology’s implementation in the semiconductor field
• Summarize current adoption status of epitaxy technology and the various epitaxy growth technologies types available on the market

Furnish an overview of epitaxy growth’s technological trends

Provide market metrics at epitaxy growth equipment for semiconductor applications

Describe the competitive landscape and identify key players in technology development

• Review the key epitaxy growth equipment suppliers and position them by application, epitaxy growth technology type, and epitaxy substrate type
• Provide a picture of the MO precursors, involved in the epitaxy growth process
Yole’s market forecast model is based on the matching of several sources:

**Comparison with existing data**
- Monitoring of corporate communication
- Using other market research data
- Yole analysis (consensus or not)

**Comparison with prior Yole reports**
- Recursive improvement of dataset
- Customer feedback

**Top-to-bottom approach**
- Aggregate of market forecasts
  - @ System level

**Bottom-up approach**
- Ecosystem analysis
  - Aggregate of all players’ revenue
  - @ System level

**Market**
- Volume (in Munits)
- ASP (in $)
- Revenue (in $M)

**Top-to-bottom approach**
- Aggregate of market forecast
  - @ Semiconductor device level

**Bottom-up approach**
- Ecosystem analysis
  - Aggregate of key players’ revenues
  - @ Semiconductor device level

**Semiconductor foundry activity**
- Capacity investments and equipment needs

**Preexisting information**

**Primary data**
- Reverse costing
- Patent analysis
- Annual reports
- Direct interviews

**Secondary data**
- Press releases
- Industry organization reports
- Conferences

**Information Aggregation**
COMPANIES CITED IN THIS REPORT

Epitaxy is the first stage in manufacturing the electronic consisting of depositing a mono-crystalline film on a mono-crystalline substrate. This stage forms the layers on the top of the base semiconductor substrate.

Epi-wafer: [raw-wafer + nucleation + buffer layer + active layer] OR [Template + active layer]

- An epi-wafer is ready to enter the Front-End line for deposition, etching, lithography, passivation... etc... steps

Epitaxy films can be categorized into two groups: “Thin” epitaxy and “Thick” epitaxy

- Thick epi layer above 20μm is considered “thick” while epi films below 20μm in total thickness is « thin »
SCOPE OF THE REPORT

Silicon Growth

Silicon ingot

Silicon Growth

Wafering

Polishing

Epi-wafer

Epi-ready wafer

Epitaxy growth process (MOCVD, CVD, MBE)

Front-end wafer

Litho, deposition, etching, metallization...

Chips: dies-on-wafer

Epi-ready wafer

Raw wafer

With no epitaxy

Epi-ready wafer

Chips: dies-on-wafer

Epi-ready wafer

Chips: dies-on-wafer

End-product

Testing

Back-end assembly

Testing
DEFINITIONS

In the field of More than Moore devices

Five key applications require epitaxy growth process in the field of MtM devices:

- **Laser diode***
  - Edge emitting laser
  - VCSEL

- **LED**
  - Traditional, microLED, miniLED
  - GaAs LED based devices (IR LED, ROY LED)
  - GaN LED based devices (UV LED, blue/green LED)

- **RF**
  - Power amplifiers, antenna switches

- **Power**
  - MOSFET
  - IGBT
  - Bipolar

- **MEMS**
  - Micromirrors
  - Gyroscopes

*so-called optoelectronic or photonic category*
Some substrate types can be hetero-epitaxy or homo-epitaxy. Also, they can have a different active layer.

<table>
<thead>
<tr>
<th>Application</th>
<th>Si/Si</th>
<th>SiC/SiC</th>
<th>GaAs</th>
<th>GaN Active layer</th>
<th>InP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser diode</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EELs</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>VCSEL</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>LED</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>RF</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Power</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>MEMS</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Main application for this material**

**In production**

**Under development/evaluation**

# Epitaxial Growth Applications and Opportunities

<table>
<thead>
<tr>
<th>Ultraviolet light</th>
<th>Visible light</th>
<th>Infrared light</th>
<th>Radiowave</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 to 380 nm</td>
<td>380 to 750 nm</td>
<td>750 nm to 10^-2 m</td>
<td>10^-2 m to 10^6 m</td>
</tr>
</tbody>
</table>

### Ultraviolet Light (UV) LED
- **Active layer**: InGaN, AlGaN
- **Substrate**: Sapphire, SiC, Si
- **Wafer size**: 4” wafer, 6” wafer, 8” wafer

### Visible Light LED
- **Blue, green LED, micro/mini LED**: InGaN, AlGaN
  - **Active layer**: InGaN, AlGaN
  - **Substrate**: Sapphire, SiC, Si
  - **Wafer size**: 4” wafer, 6” wafer, 8” wafer

### Infrared Light (IR) LED
- **Yellow, orange, red LED, Micro/mini LED**: InGaAIP, InAlGaP
  - **Active layer**: InGaAIP, InAlGaP
  - **Substrate**: GaAs
  - **Wafer size**: 4” wafer, 6” wafer

### Radiowave LED (RF, Power)
- **Ir led**: InGaAsP
  - **Active layer**: InGaAsP
  - **Substrate**: GaAs
  - **Wafer size**: 4” wafer, 6” wafer

**Substrate materials**:
- Si, SiC, Sapphire,
- GaAs, GaN, GaN/SiC

**Wafer sizes**:
- 3”, 4”, 6”, 8” wafers
## EPITAXY NON-SILICON-BASED SUBSTRATE TYPE VS APPLICATION

<table>
<thead>
<tr>
<th>Substrate type</th>
<th>End device</th>
<th>Sub device</th>
<th>End application</th>
<th>End market</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaAs active layer</td>
<td>Laser diode</td>
<td>EEL, VCSEL</td>
<td>Optical communication</td>
<td>Datacom/Telecom</td>
</tr>
<tr>
<td>InP substrate</td>
<td>LED</td>
<td>ROY LED</td>
<td>3D sensing</td>
<td>Automotive</td>
</tr>
<tr>
<td>GaN active layer</td>
<td>Laser diode</td>
<td>microLED</td>
<td>Head-mounted display</td>
<td>Consumer</td>
</tr>
<tr>
<td>SiC</td>
<td>Power</td>
<td>MOSFET IGBT</td>
<td>Wireless data transmission</td>
<td>Datacom/Telecom</td>
</tr>
</tbody>
</table>

*Silicon is the mainstream semiconductor substrate spread out in all semiconductor applications*
## EPITAXY ATTRIBUTES VS. APPLICATION REQUIREMENTS

<table>
<thead>
<tr>
<th>Devices</th>
<th>Laser diode</th>
<th>LED</th>
<th>RF</th>
<th>Power</th>
<th>Sensors / Detectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser</td>
<td>![Laser Icon]</td>
<td>![LED Icon]</td>
<td>![RF Icon]</td>
<td>![Power Icon]</td>
<td>![Sensors Icon]</td>
</tr>
<tr>
<td>Traditional LED, miniLEDs</td>
<td>![µLED Icon]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driver</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost-effective</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Growth rate</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Uniformity</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Defect</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Electrical isolating qualities</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Device sensitivity</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

### Scoring:
- **1** = Strong differentiator
- **2** = Very important
- **3** = Less critical
- **4** = Not very important or differentiating
EPI-READY WAFERS DEMAND BY APPLICATION: 2019-2025 FORECAST*

- Total epi-ready wafers (6-inch equivalent) for More than Moore applications
  - Power electronics
  - Photonics: traditional LED, miniLED, microLED, laser diode including EEL and VCSEL
  - RF electronics
  - MEMS

* in 6-inch equivalent wafers volume

2019
~7.8M

2.9M
~ 3.2M
~ 0.9M
~ 0.8M

CAGR_{2019-2025} > 18%

2025
21.3M

10.6M
CAGR: +25%

~ 8.3M
CAGR: +17%

~ 1M
CAGR: +3%

~ 1.3M
CAGR: +5%

EPITAXY EQUIPMENT MARKET FOR MORE THAN MOORE DEVICES: 2019-2025
BREAKDOWN BY TECHNOLOGY

2019  2020  2021  2022  2023  2024  2025

$7 B  $6 B  $5 B  $4 B  $3 B  $2 B  $1 B  0

MOCVD agressive  MBE agressive  HT CVD

Laser diode  microLED  Traditional LED  Power  MEMS  RF

Epitaxial growth equipment for More than Moore devices | Sample | www.yole.fr | ©2020
2018 GLOBAL EPITAXY GROWTH EQUIPMENT MARKET SHARE

Epitaxy growth equipment market share

2019 Trends will be given in the report

including MOCVD, CVD and MBE
EPITAXY EQUIPMENT SUPPLIERS: COMPETITIVE LANDSCAPE*

Top-tier CVD semiconductor equipment suppliers

Specialist MOCVD makers expert in III-V compound semiconductors

Epitaxy reactors (CVD, MBE) coming from SiC Power and high-end RF sectors

* Non-exhaustive list of companies
Epitaxy growth equipment forecasts by application segments

As well as Epitaxy growth equipment market share by semiconductor substrates
YOLE GROUP RELATED REPORTS AND MONITOR

Yole Développement

MicroLED Displays 2019

Power GaN 2019: Epitaxy, Devices, Applications & Technology Trends

Power SiC 2019: Materials, Devices, and Applications

RF GaN Market: Applications, Players, Technology and Substrates 2019

Compound Semiconductor Service – Compound Research
CONTACT INFORMATION

- CONSULTING AND SPECIFIC ANALYSIS, REPORT BUSINESS
  - North America:
    - Steve LaFerriere, Senior Sales Director for Western US & Canada
      Email: lalferriere@yole.fr - +1 310 600-8267
    - Chris Youman, Senior Sales Director for Eastern US & Canada
      Email: chris.youman@yole.fr - +1 919 607 9839
  - Japan & Rest of Asia:
    - Takashi Onozawa, General Manager, Asia Business Development (India & ROA)
      Email: onozawa@yole.fr - +81 34405-9204
    - Miho Ohtake, Account Manager (Japan)
      Email: ohtake@yole.fr - +81 3 4405 9204
    - Itsuyo Oshiba, Account Manager (Japan & Singapore)
      Email: oshiba@yole.fr - +81-80-3577-3042
    - Toru Hosaka, Business Development Manager (Japan)
      Email: toru.hosaka@yole.fr - +81 90 1775 3866
  - Korea: Peter Ok, Business Development Director
    Email: peter.ok@yole.fr - +82 10 4089 0233
  - Greater China: Mavis Wang, Director of Greater China Business Development
    Email: wang@yole.fr - +86 979 336 809 / +86 136 61566824
  - Europe & RoW: Lizzie Levenez, EMEA Business Development Manager
    Email: levenez@yole.fr - +49 15 123 544 182

- FINANCIAL SERVICES (in partnership with Woodside Capital Partners)
  - Jean-Christophe Eloy, CEO & President
    Email: eloy@yole.fr - +33 4 72 83 01 80
  - Ivan Donaldson, VP of Financial Market Development
    Email: ivan.donaldson@yole.fr - +1 208 850 3914

- CUSTOM PROJECT SERVICES
  - Jérome Azémar, Technical Project Development Director
    Email: azemar@yole.fr - +33 6 27 68 69 33

- GENERAL
  - Camille Veyrier, Director, Marketing & Communication
    Email: veyrier@yole.fr - +33 472 83 01 01
  - Sandrine Leroy, Director, Public Relations
    Email: leroy@yole.fr - +33 4 72 83 01 89
  - Email: info@yole.fr - +33 4 72 83 01 80

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