Status of Medical Imaging Equipment and Detectors 2020

Market and Technology Report 2020
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GLOSSARY

- APS: Active Pixel Sensor
- AMLCD: Active-Matrix LCD
- a-Se: Amorphous Selenium
- a-Si: Amorphous Silicon
- CsI: Cesium Iodide Scintillator
- BSI: Backside Illumination
- CAGR: Compound Average Growth Rate
- CBCT: Cone Beam Computed Tomography
- CCD: Charge Coupled Device
- CdTe: Cadmium Telluride
- CIS: CMOS Image Sensor
- CMOS: Complementary Metal Oxide Semiconductor
- cMUT: Capacitive Micromachined Ultrasound Transducer
- CT: Computed Tomography
- DQE: Detective Quantum Efficiency
- EM: Electro-Magnetic
- ENT: Ear-Nose-Throat
- FO: Fiber-optic
- FOP: Fiber-optic Plate
- FPD: Flat-Panel Detector
- FSI: Front-Side Illumination
- GI: Gastrointestinal
- IS: Image Sensor
- IVUS: Intra Vascular UltraSound
- LED: Light-Emitting Diode
- MRI: Magnetic Resonance Imaging
- NOTES: Natural Orifice Transluminal Endoscopic Surgery
- OCT: Optical Computed Tomography
- OEM: Original Equipment Manufacturer
- PET: Positron Emission Tomography
- pMUT: Piezoelectric Micromachined Ultrasound Transducer
- RF: Radio frequency
- TDI: Time-Delayed Integration
- TFT: Thin-Film Transistor
- SiPM: Silicon Photomultiplier
- SNR: Signal to Noise Ratio
- SPAD: Single-Photon Avalanche Diode
- SPECT: Single-Photon Emission Computed Tomography
- SPD: Single-Photon Detection
- TSV: Through Silicon Via
COMPANIES CITED IN THIS REPORT

SCOPE OF THE REPORT

Molecular imaging
- SiPM
- CZT
- Photomultiplier tubes

Ultrasound
- Ultrasound transducers
- RF coils

MRI

Endoscopy
- CCD
- CMOS image sensors
- OCT

Ultrasound imaging
- Photodiode arrays

Medical imaging

X-RAYS
- Flat panel displays

Your needs are out of scope of this report?
Contact us for a custom study:
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’s analysis (consensus or not)

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

**Top-down approach**
- Aggregate of market forecasts
  - @ System level

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

**Market**

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

**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**
The Yole Group of Companies, including Yole Développement, System Plus Consulting, Knowmade and PISEO, are pleased to provide you a glimpse of our accumulated knowledge.

Feel free to share our data with your own network, within your presentations, press releases, dedicated articles and more. But before that, contact our Public Relations department to make sure you get up-to-date, licensed materials.

We will be more than happy to give you our latest results and appropriate formats of our approved content.

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WHAT WE GOT RIGHT, WHAT WE GOT WRONG

- Our market data for reusable endoscopy and capsule endoscopy was correct and we anticipated the arrival of the videoscope.

- We anticipated the arrival of IGZO in the X-ray market as well as the technological change from CCD to CMOS in interventional imaging.

- We anticipated the arrival of SiPM in the molecular imaging market.

- We could not forecast the COVID-19 pandemic and therefore the impact it would have on the global medical imaging business and on the global economy.

- We did not anticipate the adoption of disposable endoscopes to be so rapid (due to regulations).

- We did not anticipate such a rapid arrival of point of care ultrasound and OCT (technological breakthrough).

- Our market data for SPECT was a little bit high, and we have corrected it.

Our 2017 report did not cover MRI, this one does.
HISTORICAL SYNERGIES BETWEEN MODALITIES AND TECHNOLOGIES

Modalities & systems

XIX
- X-Ray apparatus discovered
- Ultrasound
- CT scanner
- MRI

XX
- Intra-oral sensor
- Micro camera endoscopy
- Intra-oral detector
- Chip to the tip endoscope
- Portable ultrasound
- Photo-counting CT

XXI
- GE – PET/CT
- Siemens 7T MRI

Sensor

1920
- PM tubes
- Analogue X-ray film

1980
- CCD

1990
- CMOS

2005
- SiPM
- CdTe-based technologies
- Micro camera endoscopy

2015
- TFT IGZO
- cMUT

Semiconductor technologies

2018
- GE flexible MR coils
<table>
<thead>
<tr>
<th>Main contrast</th>
<th>Advantages</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>X-ray (radiography + CT scan)</strong></td>
<td>• High-density tissue</td>
<td>• Expensive • Not widely available • Slow</td>
</tr>
<tr>
<td><strong>MRI</strong></td>
<td>• Soft tissue</td>
<td>• Expensive • Not widely available • Slow</td>
</tr>
<tr>
<td><strong>Ultrasound</strong></td>
<td>• Echogenic tissue</td>
<td>• Expensive • Not widely available • Slow</td>
</tr>
<tr>
<td><strong>Molecular imaging</strong></td>
<td>• Contrast agent with specific targets</td>
<td>• Radiation exposure • Very expensive • Not widely available</td>
</tr>
<tr>
<td><strong>Endoscopy</strong></td>
<td>• Video of visible tissue</td>
<td>• Radiation exposure • Very expensive • Not widely available</td>
</tr>
<tr>
<td><strong>OCT</strong></td>
<td>• Low depth soft tissue</td>
<td>• Can be invasive (inside a hole/cavity/surgery) • Issues with sterility</td>
</tr>
</tbody>
</table>

**Advantages**
- **X-ray**
  - High-density tissue
  - Widely available
  - Very high contrast on high-density tissue
  - “See through” imaging
  - 3D available
- **MRI**
  - Soft tissue
  - Very high contrast in soft tissue
  - Versatile (multiple different sequences for multiple contrasts)
  - “See through” imaging
  - 3D available
- **Ultrasound**
  - Echogenic tissue
  - Cheap
  - Widely available
  - “See through” imaging
  - 3D available
- **Molecular imaging**
  - Contrast agent with specific targets
  - Versatile
  - Highly sensitive
  - “See through” imaging
  - 3D available
- **Endoscopy**
  - Video of visible tissue
  - Cheap
  - Widely available
  - Fast
- **OCT**
  - Low depth soft tissue
  - Versatile
  - High sensitivity
  - OCT-A
  - View in-depth
  - Miniaturization

**Drawbacks**
- **X-ray**
  - Radiation exposure
- **MRI**
  - Expensive
  - Not widely available
  - Slow
- **Ultrasound**
  - Expensive
  - Not widely available
  - Slow
- **Molecular imaging**
  - Radiation exposure
  - Very expensive
  - Not widely available
- **Endoscopy**
  - Expensive
- **OCT**
  - Low depth (intravascular)

---

**X-ray** is well-positioned in the medical imaging landscape as a “see-through” imaging modality that is widely available and offers a very high contrast on high-density tissue. However, other modalities (e.g. MRI) are taking some CT-scan share in the 3D area because MRI is a non-invasive technique that does not require radiation exposure and offers excellent resolution.
WHAT IS SOLID-STATE?

Technology transformation

In this report, « solid-state » refers to electronic components, devices, and systems based on semiconductor and IC processes.
X-RAY TECHNOLOGY - COMMERCIAL ROADMAP

**CCD – Image intensifier**
- Improved quality
- Digitalization

**a-Si flat panels**
- Lower cost
- Higher integration

**a-Se**
- Direct conversion

**CMOS flat panels**
- Lower dose
- Higher speed and resolution

**IGZO**
- Better cost efficiency
- Lower noise

**Photon counting**
- Spectral imaging
- High image quality

- **Performance**
- **Time**
- **Year of market introduction**
- **1980s**
- **2010s**
- **2021**
- **2024**
**ENDOSCOPY ROADMAP**

Reusable fiberscopes for rigid and flexible endoscopy

Reusable videoscopes for rigid and flexible endoscopy

Capsule endoscopy

Disposable endoscopy for specific applications (small diameter and difficult to decontaminate)

Disposable endoscopy widely spread in terms of applications (going for gastroenterology) and technologies (rigid and flexible endoscopes)

Fiberoptic image guides: key enablers for fiberscopes, will gradually disappear

Camera modules: key enablers for videoscopes but will be replaced by disposable products

Very small camera modules with high volume production capabilities: key enablers for disposable products

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The development of solid-state sensors, especially SiPM, has enabled the combination of PET with MR.

Initial PET scans were standalone machines... ... rapidly, PETs were combined with CT scanners... ... thanks to solid-state sensors, PET/MR was made possible.

PMT has had a wide use in molecular imaging

Solid-state (SiPM, APD, CZT...)

Solid state sensors have seen a rapid adoption as they add benefits such as MR compatibility

Thanks to the development of CZT, SPECT systems are transitioning from PMT to solid-state
Successive technologies developed that now coexist.

- **Bulk Piezoelectric – PZT ceramic**
  - Conventional technology for ultrasonography

- **Bulk Piezoelectric – PZT ceramic**
  - Next generation technology for ultrasonography targeting high sensitivity applications

- **cMUT technology**
  - Unveiled in 2009 for ultrasonography cart based. New generation cMUT unveiled in 2017 for point of care imaging

- **pMUT technology**
  - To be commercialized in 2021 – 2022 for medical and consumer healthcare applications
There is a market for OCT outside the specialist’s office. Systems can be installed at retail stores or optician’s shops, or even directly in a patient's home.

- Better disease monitoring
- Free up ophthalmologists’ waiting lists
- Better monitoring of drug effectiveness by pharmaceutical companies

However, the product must have a good cost to performance ratio.

USA: As of 1st July 2020, the CPT (0604T) has registered OCT for home applications.
MAGNETIC RESONANCE IMAGING (MRI) - POINT OF CARE MRI

New developments in small MRI

Point of care MRIs were a trend a decade ago which ultimately failed. However, we now see a new revival of such products.

Hyperfine and Aspect imaging offer POC systems. It was apparently a trend a few years back but now the big players have gone to bigger, not smaller. This does leave a niche market in the order of tens of million $ for small players such as these start-ups.
HYBRIDIZATION
Toward multimodalities for better diagnosis

What are the drivers for the development of multimodality:

• First the application itself. For instance, the combination of PET and CT scanners allows a complementary acquisition and therefore offers more accurate diagnostic information.

• The second is the available technology. Indeed, in the case of PET/MR, this was made possible thanks to the development of high magnetic field compatible sensors such as SiPM.

• The third is the availability of two or more complementary technologies. In the case of catheter based intravascular diagnosis, the use of IVUS allowed to image the tissue in depth. Adding OCT for intravascular complements what IVUS can image. In some cases, it is even possible to combine both technologies to take advantage of both worlds.
TOWARD HIGH VOLUMES MARKETS IN MEDICAL IMAGING

Semiconductor technologies are key enablers of this market transformation

2 different roads to reach high volume markets: disposable products and point of care devices.

Disposable products (Endoscopy)

- **Drivers**: disinfection, availability, efficiency
- This means 1 procedure = 1 product : High volume market

Point of care devices (Ultrasound and OCT)

- **Drivers**: availability, affordability
- Today, OCT and ultrasound systems are bulky and necessitate specialists to handle them. Point of care systems are targeting non specialists and widespread usability (nurse’s office, optician, home, etc.)

Key enabler:
Low cost/high volume production of camera modules

Key enabler:
Low cost/high volume production of micromachined ultrasound transducers (cMUT/pMUT)

Handheld ultrasound to replace stethoscopes?
MARKET DATA AND FORECASTS

Some definitions

The data is expressed as follows:
- By volume (units)
- By market value ($M)

Detector/module/camera

**X-ray detector = sensor + scintillator (if needed) + ASIC**

**Endoscopy camera module = image sensor + optics + ASIC**

Sensor

**e.g.: a-Si flat-panel detector, CMOS intraoral detector, ultrasound transducer, SiPM**

**Sensor**

**e.g.: CMOS image sensor, photodiodes**
**MEDICAL IMAGING EQUIPMENT LANDSCAPE**

Yearly global spending*

<table>
<thead>
<tr>
<th>Spatial resolution</th>
<th>Endoscopy $6B</th>
<th>X-ray $17B</th>
<th>MRI $5B</th>
<th>Molecular Imaging $3B</th>
</tr>
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<tbody>
<tr>
<td>10 mm</td>
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<td>100 nm</td>
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<tr>
<td>No depth</td>
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<tr>
<td>1 mm</td>
<td>OCT $1B</td>
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<tr>
<td>10 cm</td>
<td>Ultrasound $6B</td>
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<td>10 cm</td>
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</table>

* Equipments only, service and consumables not included
Medical imaging, a global market worth $38B with four main players.
DETECTORS FOR MEDICAL IMAGING EQUIPMENT MARKET
By Modalities (in $M)

- **X-ray**
  - 2019: $2.3B
  - CAGR 19-25: +7.3%
  - 2025e: $6.6B

- **Ultrasound**
  - 2019: $0.3B
  - CAGR 4%
  - 2025e: $0.6B

- **Endoscopy**
  - 2019: $0.2B
  - CAGR 14%
  - 2025e: $3M

- **Molecular Imaging**
  - 2019: $0.3B
  - CAGR 16%
  - 2025e: $6M

- **OCT**
  - 2019: $0.3B
  - CAGR 14%
  - 2025e: $3.7B

- **Other**
  - 2019: $0.2B
  - CAGR 8%
  - 2025e: $2B

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MARKETS TRENDS

Examples of slides
Artificial Intelligence for Medical Imaging 2020

X-Ray Detectors for Medical, Industrial and Security Applications 2019

BioMEMS Market and Technology 2020
OmniVision’s OVM6948 CameraCubeChip

Butterfly Network iQ CMUT Sensor
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