Agenda

• Overview of Image Sensors Technologies
• Zoom on X-Ray and Endoscopy applications
• Image sensors Market Data
• Perspectives
Image sensors Technologies
Image Sensor Technologies over time

- **Analog film**
- **Computed radiography**
- **CCD cameras**
- **a-Si Flat panels**
- **CMOS Flat panels**
- **Single Photon Counting**

<table>
<thead>
<tr>
<th>1900’s</th>
<th>1980’s</th>
<th>1990’s</th>
<th>2000’s</th>
<th>2010’s</th>
<th>2020’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog film</td>
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</tr>
</tbody>
</table>
CCD Image Sensors: Technology Description

• **Principle:**
Photons are converted into electrons in each pixel, and then pixels are transferred sequentially row by row in an horizontal register which converts charges into voltage pixel by pixel.

• **Specific features:**
- Excellent image quality
- Need separate chips for digitalization & processing
- High power consumption
- Limited speed

• **Main manufacturers:**
CMOS Image Sensors: Technology Description

• **Principle:**
CMOS image sensors have the distinction to have in-pixel amplification and charge-to-voltage conversion.

• **Specific features:**
- Highly integrated
- Small form factor
- Low cost in mobile applications, high cost for large X-ray imaging applications
- Low power consumption
- High readout speed

• **Main medical CMOS image sensors manufacturers:**

- Omnivision
- Aptina
- ON Semiconductor
- AWAIBA
- Plus Pixel

• **Main open CMOS foundries for medical image sensors:**

- TowerJazz
- FAB
- Dongbu
CCD vs. CMOS Architectures

- CCDs move photo-generated charge from pixel to pixel and convert it to voltage at an output node.
- CMOS imagers convert charge-to-voltage directly inside each pixel!
a-Si Flat Panels: Technology Description

- **Principle:**
  Electrons are accumulated in photodiodes and then transferred by switching a thin-film transistor addressed by a line pulse. The signal is readout by an external amplifier and analog-to-digital converter.

- **Specific features:**
  - Very large area
  - Low cost
  - Low resolution
  - Low readout speed

- **Main medical a-Si flat panel manufacturers:**

  ![a-Si readout matrix architecture – Courtesy of Varian](image)

  ![CMOS image sensors - Pre-processing is monolithically integrated on the same chip](image)
X-Ray & Endoscopy
## Medical Image Sensors: Market Segmentation

<table>
<thead>
<tr>
<th>Applications</th>
<th>Direct Imaging / Hardware Dependant</th>
<th>Indirect Imaging / Software Dependant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Microscopy</td>
<td>MRI</td>
</tr>
<tr>
<td>Standalone</td>
<td>Endoscopy</td>
<td>Ultrasound Imaging</td>
</tr>
<tr>
<td>Disposable</td>
<td>Camera pills</td>
<td>Nuclear Medicine</td>
</tr>
<tr>
<td>Re-usable</td>
<td>Disposable endoscopes</td>
<td></td>
</tr>
<tr>
<td>Integrated</td>
<td>Flexible endoscopes</td>
<td>Doppler ultrasound</td>
</tr>
<tr>
<td>into a large system</td>
<td>Rigid endoscopes</td>
<td></td>
</tr>
<tr>
<td>Microscopes</td>
<td>X-Ray imagers for intra-oral imaging</td>
<td>CT</td>
</tr>
<tr>
<td></td>
<td>X-Ray imagers for 3D &amp; large area imaging</td>
<td>MRI system</td>
</tr>
<tr>
<td></td>
<td>X-Ray imagers for 2D extra-oral imaging</td>
<td>PET Scan</td>
</tr>
</tbody>
</table>

### In the following slides, we will focus on the Endoscopy and X-Ray Imaging applications
Medical Image Sensors: Market Segmentation

For each product category, Medical Image Sensors require different functions:

<table>
<thead>
<tr>
<th>Image sensors functions</th>
<th>Camera pills</th>
<th>Disposable endoscopes</th>
<th>Flexible endoscopes</th>
<th>Rigid endoscopes</th>
<th>X-Ray imagers for dental intra-oral imaging</th>
<th>X-Ray imagers for 2D dental extra-oral imaging</th>
<th>X-Ray imagers for 3D CBCT &amp; large area imaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well established</td>
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<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Low power consumption</td>
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<tr>
<td>High integration: Small size</td>
<td>X</td>
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<td>Low cost</td>
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<tr>
<td>Biocompatibility</td>
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<tr>
<td>Increase resolution</td>
<td>X</td>
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<td>X</td>
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<td>X</td>
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<td>X</td>
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<tr>
<td>Wide field of view</td>
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<tr>
<td>High sensibility/DQE (low X-ray dose)</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Temperature and Humidity Resistance</td>
<td>X</td>
<td>X</td>
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<td></td>
<td>X</td>
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<tr>
<td>Radiation hardness</td>
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<td>X</td>
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<td>Emerging</td>
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<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Multi-spectral imaging</td>
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<tr>
<td>Multi-modalities</td>
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<td>X</td>
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<tr>
<td>3D imaging</td>
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</tr>
</tbody>
</table>

* Key Medical Image Sensor functions per product category
Image Sensors Positioning: Price/Volume Mapping

Image sensor price (In $)

$1000

$100

$1

1,000 units

10,000 units

100,000 units

X-ray Imaging

Low volume / High value applications

Optical Imaging

High volume / Low value applications

X-Ray imagers for large area and 3D extra oral imaging

X-Ray imagers for intra-oral imaging

X-Ray imagers for 2D extra-oral imaging

Rigid Endoscope

Flexible Endoscope

Disposable Endoscopes

Camera Pill

Image sensor Volume (in units/year)
Image Detection: Technological Differences Between X-Ray and Endoscopy Imaging

Endoscopy Application
- Visible radiation can be focused and absorbed by classical layer of silicon
- Optical systems focus light on small sensors

X-Ray Imaging Application
- X-rays cannot be focused with an optical system
- Size of x-ray detectors must be larger than the area to image
- X-rays cannot be absorbed by classical layer of silicon

Visible radiation can be focused and absorbed by classical layer of silicon
Optical systems focus light on small sensors

X-rays cannot be focused with an optical system
Size of x-ray detectors must be larger than the area to image
X-rays need a special conversion material

- Classical CCD sensor + bulky magnification system
- a-Si flat panel
- Tiled wafer-scale CMOS sensors
- Scintillator layer on top of visible image sensor: CCD, CMOS or a-Si
- Photoconductor layer on top of an a-Si or CMOS readout circuit

These differences explain the strong ASP variation
# Image Sensor Technologies by Market

<table>
<thead>
<tr>
<th>Endoscopy Application</th>
<th>CCD</th>
<th>CMOS</th>
<th>A-Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera pills market</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Disposable endoscopes market</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Flexible endoscopes market</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Rigid endoscopes market</td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>intra-oral imaging market</td>
<td></td>
<td>X</td>
<td></td>
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<tr>
<td>X-ray 3D CBCT extra-oral imaging</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2D extra-oral market</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D &amp; large area market</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>X-Ray Imaging Application</th>
<th>CCD</th>
<th>CMOS</th>
<th>A-Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D extra-oral market</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D &amp; large area market</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

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## Medical Image Sensors Adoption Curves

### Medical Image Sensors Market Penetration

<table>
<thead>
<tr>
<th>Application maturity</th>
<th>Emerging</th>
<th>Growing</th>
<th>Mainstream</th>
<th>Declining</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>X-Ray General Imaging</strong></td>
<td>CMOS</td>
<td>Amorphous Silicon</td>
<td>CMOS</td>
<td>Computed Radiography</td>
</tr>
<tr>
<td><strong>X-Ray Dental Imaging</strong></td>
<td>CMOS</td>
<td>CCD new generation</td>
<td>CMOS</td>
<td>CCD</td>
</tr>
<tr>
<td><strong>Rigid Endoscopes</strong></td>
<td>CMOS</td>
<td>CCD new generation</td>
<td>CCD</td>
<td></td>
</tr>
<tr>
<td><strong>Flexible Endoscopes</strong></td>
<td>CMOS</td>
<td>CCD new generation</td>
<td>CCD</td>
<td></td>
</tr>
<tr>
<td><strong>Camera Pills</strong></td>
<td>CCD</td>
<td>CMOS</td>
<td>CMOS</td>
<td></td>
</tr>
<tr>
<td><strong>Disposable Endoscopes</strong></td>
<td>CMOS</td>
<td>CMOS</td>
<td>CMOS</td>
<td></td>
</tr>
</tbody>
</table>

**Applications too young to identify mainstream/declining technology**
Given Imaging: Pillcam SB2®

• **Company**
Given Imaging is a world leader in GI medical devices, offering the broadest portfolio of capsule solutions to visualize the gastrointestinal tract and, through its Sierra Scientific subsidiary, offers specialty GI diagnostic solutions and high-resolution manometry. The company is based in Israel.

Turnover 2011: $178 M

• **Application**
Patient-friendly tool for visualization of the entire small bowel and is the standard of care for detecting small bowel abnormalities. It is the only capsule endoscope indicated for use in pediatric.

• **Features**
- Size: 11mm x 26mm
- IS technology: CMOS
- The video capsule contains an imaging device and light source and transmits images at a rate of two images per second, generating more than 50,000 pictures during the eight-hour procedure.
Medigus: The SRS System

• **Company:**

Medigus is a medical device company that specializes in developing innovative endoscopic procedures and devices. Medigus is a pioneer developer of a unique proprietary endoscopic device: The SRS systems

• **Application:**

The medical device is dedicated for the treatment of GERD, one of the most common chronic diseases in the western world.

• **Features:**

- IS technology: CMOS
- Provides the same results as in gold standard laparoscopic surgery.
- Faster than laparoscopic surgery.
- A more attractive treatment than either surgery or lifelong medication.
- A more efficient and cost effective procedure.
- Less trauma to patient with no incisions.
- **The entire endoscope is disposable.**
e2v: intra-oral Detectors

- **Company**
e2v (headquartered in Chelmsford, UK) is an independent supplier of intra-oral x-ray detectors. E2v supplies two intra-oral detectors, as stand-alone units with software development kits to OEMs.

- **Positioning**
e2v has initiated major innovations in the dental intra-oral market: the first stand-alone USB detector to ease integration by OEM, and patented a CMOS sensor with 4 clipped corners to increase patient comfort by removing sharp edges of the detector.

- **Application**
  intra-oral X-ray imaging

- **Features:**
  - Detector active size: 20x 30 mm² or 26x 36 mm²
  - CMOS sensor with patented 4 clipped corner design
  - Pixel pitch: 19 µm
  - Dynamic range: 70dB
  - Scintillator: CsI + FOP (Fiber Optic Plate)
RF System Lab: Multi-CCD X-Ray Detector

- **Technology**
  NAOMI is composed of several multilayer boards that are each composed of 12 CCD chips controlled by a single command. Each board consists of 10 layers of substrates to avoid interaction between signal lines.

- **Visualization**
  Each CCD sensor visualizes a limited part of the field of view. Final x-ray image is reconstructed by stitching individual images.

[Image of multi-CCD X-Ray Detector]
Market Considered

**Applications**

- Endoscopy Imaging
  - Camera pill market
  - Disposable endoscope market
  - Flexible endoscope market
  - Rigid endoscope market

- X-ray Based Imaging
  - intra-oral imaging market
  - X-ray 3D CBCT extra-oral imaging
  - 2D extra-oral imaging market
  - 3D & large area imaging market

**Markets**

- Camera pill market
- Disposable endoscope market
- Flexible endoscope market
- Rigid endoscope market
- intra-oral imaging market
- X-ray 3D CBCT extra-oral imaging
- 2D extra-oral imaging market
- 3D & large area imaging market

**Image sensors technologies**

- CMOS image sensors
- CCD image sensors
- CMOS image sensors
- CCD image sensors
- Amorphous Silicon
The global Medical Image Sensor market will grow from $68M in 2011 to $112M in 2017.
The global Medical Image Sensors market in volume will grow from 1.4 Munits in 2011 to 4.6 Munits in 2017, fueled by emerging endoscopy products: camera pills and disposable endoscopes.
Endoscopy Imaging: Split CCD/CMOS (in $M)

The CCD Medical Image Sensors market dedicated to endoscopy will grow from $4M in 2011 to $5M in 2017.

In parallel, the total CMOS Medical Image Sensors market will continue to grow sharply from $1M in 2011 to $3.5M in 2017.
X-Ray Imaging: Split CCD/CMOS/a-Si (in M$)

X-Ray market forecasts
CCD/CMOS/a-Si sensors revenues

CAGR_{2012-2017} = 12%
CAGR_{2012-2017} = 3%
CAGR_{2012-2017} = 6%

Medical IS Market for X-Ray application will grow from $63M to $103M in 2017

CMOS x-ray image sensors revenue will continue to grow at a 12% CAGR_{2012-2017} and reach $44M in 2017.
Perspectives
Medical Image Sensors technology is the gateway for new entrants in Endoscopy Market!
Future Trends in Endoscopy

- Therapeutics Endoscopy

  OPEN SURGERY
  The growing awareness that the degree of invasiveness of surgery has a large impact on patient outcomes

  LAPAROSCOPE
  Size reduction
  More and more features integrated
  Continued evolution of flexible endoscopy into more of a therapeutic tool

  ENDOSCOPE FOR NOTES
  Natural Orifice Transluminal Endoscopic Surgery

  ENDOSCOPE

- Increase the use of CMOS MIS
  Camera Pills ➔ Colonoscopy application
  Disposable endoscopy ➔ Drivers: Sterilization efficiency, Downtime reduction, Cost reduction
  Chip to the tip endoscope
  Invasiveness reduction

- 3D imaging
Future Trends in X-Ray Imaging

3 different trends will shape the future of x-ray systems:

1. The current move to CMOS
2. The move from indirect to direct conversion of x-ray (no scintillator, no fiber optic plate)
3. The move toward single photon detectors

**CMOS FPD**
- Firstly introduced in 2000 by Rad-Icon & Hamamatsu
- Currently being adopted

**Direct conversion**
- Enables higher resolution
- Already commercialized with a-Si, compatible with CMOS
- Next step is crystalline photoconductors, e.g. CdTe

**Single photon counting**
- Complex ASIC
- Lower dose
- Open new possibilities like multi-spectral imaging
- Beyond 2017

Courtesy of Rad-Icon

Courtesy of ANRAD

Courtesy of Siemens
CMOS flat panels detectors will position on applications that require medium size panels AND high resolution OR high speed. Contrary to a-Si panels, CMOS needs no compromise low dose and high imaging speed.

- Typical applications are mammography (high resolution) or fluoroscopy (real-time imaging)
X-Ray Imaging: Technologies & Targeted Applications

- a-Si
- CCD
- CMOS

Growing

Mature

Emerging

Detector size

- Dental intra-oral
- Dental extra-oral
- Cardiology
- Fluoroscopy
- Mammography
- General Radiography
Conclusions
Summary and conclusions

- The global market of Medical Image Sensors will grow from $68M in 2011 to $112M in 2017.

- Whereas the contribution in value of the global endoscopy market represents only a few 10% of the Medical Image Sensors market in 2011, 90% is related to X-Ray applications.

- Image Sensor Innovations are reshaping the Medical Imaging Industry as it permit the entry of news market players, the development of news products in line with both patient and physicians requirements.

- The medical image sensors market is currently evolving, emerging technologies mentioned in the presentation are expected to go mainstream in the future, fueled by new applications with high growth rates.
Thank You!

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