Cost-effective uncooled InGaAs SWIR image sensors and how to use them in Machine Vision

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Introduction
What is SWIR Imaging?
Sofradir Group

- Global leader in Infrared Technologies
- 30+ years of experience
- ~1000 employees
Infrared Regions

Reflective Light

Thermal Radiation

- **SWIR**: 0.4 µm
- **MWIR**: 0.9 µm
- **LWIR**: 2.5 µm
- **VLWIR**: 10 µm
- **15 µm**
Sofradir Technologies

SWIR

MWIR

LWIR

VLWIR

0.4µm 0.9µm 2.5µm 10µm 15µm

(TEC Cooling)

MCT (Cryogenic Cooling)

InGaAs (TEC Cooling)

or

InSb (Cryogenic Cooling)

QWIP (Cryogenic Cooling)

Microbolometer (Uncooled)
Light-Material interaction depends on wavelength

Using light outside of visible enables detection of features out of reach for the human eye (ex: operators) and for CMOS/CCD sensors

SWIR light is reflective: Similar implementation as visible cameras
### A Few Examples

<table>
<thead>
<tr>
<th>Application: Wafer inspection</th>
<th>Application: Moisture detection</th>
<th>Application: Surveillance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Silicon</strong> is opaque in Visible but transparent above 1100nm</td>
<td><strong>Water</strong> is transparent in Visible but opaque in SWIR</td>
<td><strong>Reduced atmospheric scattering at longer wavelengths</strong></td>
</tr>
</tbody>
</table>

**Visible** | **SWIR** | **Visible** | **SWIR** | **Visible** | **SWIR**
Applications for SWIR Imaging
Semiconductors

⇒ Largest Machine Vision market by revenue

• Silicon becomes transparent above 1100nm
  ⇒ Inspection of defects through ingots and wafers
  ⇒ Alignment of 3D ICs
  ⇒ Failure analysis, quality control

• Photovoltaics
  ⇒ Luminescence imaging emitting in SWIR
  ⇒ Detection of defects
  ⇒ Quantification of cells efficiency
Spectral Imaging for Sorting

Collection of Spectral Information for Material Analysis

- Non-destructive
- Non-invasive
- Chemical-free
- 100% screening
- Instant results
- In-line compatible

SWIR

Organic Materials Chemicals
Example: Food Products

Automatic in-line quality assessment

Fruits, Vegetables, Cereals
- Total soluble solids (Sugars)
- Total acidity
- Moisture content
- Defects detection
- Infections, diseases, contamination

Fish & Meat
- Protein and Fat content
- Moisture
- Collagen
- Bone residues
Example: Soil and Vegetation

Monitoring health of cultures and soil composition thanks to spectral imaging in SWIR

- Targeted use of water and agrochemicals
- Early detection of diseases
- Better prediction of yields and risks

\[ \lambda = 1649 \text{nm} \]
Example: Recycling

Hyperspectral SWIR cameras enable recognition and sorting of the main types of plastic used in consumer applications.
**Surveillance Benefits**

SEEING BEYOND VISIBLE LIGHT

**SWIR Abilities:**
- Improved contrasts in challenging atmospheric conditions (fog, haze, smog, ...)
- Images through glass (Windows, windshields, etc...)
- Identification capabilities (Imaging with shadows and contrasts)
- Laser spot detection

**Poor weather conditions**
Reduced scattering compared to visible

**VISION Days**
2018

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SWIR InGaAs Detectors
InGaAs Detectors


III-V Detection Circuit

Hybridization process

AR coating

InP Substrate

InGaAs Absorption Layer

CMOS Read-Out Circuit

Quantum Efficiency (%)

Typical CMOS

InGaAs

Visible

NIR

SWIR

\( \lambda_{on} = 0.9 \mu m \)

\( \lambda_{off} = 1.7 \mu m \)

\( \lambda (nm) \)

300 500 700 900 1100 1300 1500 1700 1900

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TEC Cooled InGaAs Sensor

- Sapphire window
- Hybridized chip
- Interconnection ceramic
- Packaging
- Thermoelectric cooler

SNAKE SW

- VGA – 640x512
- 15µm pitch
- High speed – 300FPS
- Low readout noise and dark current
- Best available SWIR image quality
Temperature Impact on InGaAs

- InGaAs has higher dark current ($I_{dc}$) than visible sensors

- Dark signal ($S_{dc}$) reduces Dynamic Range
  - Exponential increase with Temperature
  - Linear increase with integration time

- Dark current noise ($N_{dc}$) reduces SNR

\[
S_{dc}(e^-) = I_{dc}(A) \times \frac{T_{\text{int}}}{e}
\]

\[
N_{dc} = \sqrt{S_{dc}}
\]
Sofradir InGaAs Technology

- Leading edge InGaAs detection layer quality for best-in-class dark current performance
  \[ I_{dc} = 30fA @ \text{ambient temperature} \]

Conditions for Good Performance without cooling

- Tint < 1ms at High Gain
- Tint < 100ms at Low Gain

Cooling required

- Very low light applications requiring High Gain and long exposures
Machine Vision Applications

- Require short Tint for inspection of fast moving objects
- Can / Have to provide illumination

- Uncooled operation of the Snake SW detector possible without sacrificing performance
- Snake SW enables operation up to 300FPS with VGA format, compatible with in-line sorting equipment implementation
Uncooled InGaAs Sensor

SNAKE SW TECLESS

- World’s smallest SWIR VGA (16.5mm square)
- Cost optimized uncooled detector
- Ideal choice when dark current impact is minimal: High illumination / Low integration time
Typical Implementation

**Proximity Electronics**
- Analog to digital conversion (2 to 8 channels)
- Power supply to sensor
- Available off the shelf Sofradir Megalink board

**Processing Electronics**
- Image correction, application specific SW

- BPR: Bad Pixels Removal
- NUC: Non-uniformity Correction
- AE: Auto-Exposure

Interface Electronics
- Input/Outputs

Simplified by Snake leading edge SWIR image quality:
- 99.7% typical Bad Pixels and 4% Non-Uniformity
Conclusions
Conclusions

- SWIR Imaging enables collection of “invisible” information for solving new challenges in Machine Vision

- SWIR Spectral Imaging can provide material and chemical composition of products in-line

New generation InGaAs detectors with high speed and low noise can be operated uncooled with minimal impact on performance, thus offering an affordable sensor solution
SNAKE SW TECLESS

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AND SURVEILLANCE
APPLICATIONS