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Specialty Techniques for Monitoring Process Temperature & Gas Concentrations

Phosphorescent Decay
Infrared Radiation
Photoacoustic Spectroscopy

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LumaSense Is A Global Company With Decades of Experience In Multiple Sensing Technologies

LumaSense Technologies Key Facts:
- ~250 employees in nine sites worldwide
- Multiple Decades of experience serving various OEMs
- Deep applications engineering talent in multiple disciplines
- Core competency in gas analysis
- Financial strength and profitability
- Offices in 9 countries
- Headquarters in California, USA

Five product families all based on different types of optical technologies
- Two gas analysis product families based on distinct technologies
  - Non-Dispersive Infrared
  - Dispersive Infrared
  - Photo-Acoustic Spectroscopy
- Three temperature product families
  - Fiber optic
  - Non-Contact Infrared (pyrometers)
  - Thermal Imaging
**Luxtron Fluoroptic: Benefits / Advantages**

**Immune**
- Unaffected by EMI, Microwave and RF Interferences
- Electrically Non-conductive Fiber Optic Temp Probes

**Inert**
- Chemically Inert, Inorganic Ceramic Sensor
- Stable, Self-calibrating/auto gaining System

**Invisible**
- Minimally Intrusive (Probes as Small as 200µm dia)
Measurement is Based on a Temperature Sensitive Phosphorescent Sensor Attached to the Probing End of a Fiber Optic Cable

Electronics Measure the Decay Time of the Fluorescence that is Temperature Dependent

A Single Optical Fiber Transmits Both the Excitation and the Fluorescence Signal

Depending on probe construction, measures temperatures btw -100C & +330C
Luxtron Fluoroptic: Operating Principle

Spectra of Temperature Sensitive Phosphorescent Ceramic

Decay Time of Emitted Light is Proportional to Temperature

Plot Representation of Method for Extracting Fluorescent Decay Time
Luxtron Fluoroptic: Standard Instruments

R & D Lab End-User Instruments
- 812 (2 chnl, 2-4 Hz)
- FOT Lab Kit (4 chnl, 1-4 Hz)

OEM Modules
- M600 (1-4 chnl, 1-4 Hz)
- 800 (1-2 chnl, 2-10 Hz)

Closed Loop Control Systems
- ThermAsset2 (2-8 chnl, 6 relay)
- LumaSMART (2-16 chnl /relay)
Luxtron Fluoroptic: Standard Probe Schematics

- PFA Teflon encapsulation
- Fused PFA Teflon sealant
- Silicone se
- Ceramic tube
- Phosphor sensor
- Jacket
- Optical Fiber Core
- Clear Elastomer
- Cladding
- Low Thermal Conductivity of Elastomer Provides Thermal Isolation of Sensor
- Phosphor Layer Compressed Against Surface for Good Thermal Contact

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Luxtron Fluorooptic: Standard Probes

STF - fast response immersion

<table>
<thead>
<tr>
<th>Temperature Range</th>
<th>0 to 295 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response Time</td>
<td>1.25 seconds in still air, 250 milliseconds in water</td>
</tr>
<tr>
<td>Connector Type</td>
<td>ST</td>
</tr>
</tbody>
</table>

LumaSense Technologies
Luxtron Fluoroptic: Custom OEM Probes
Luxtron Fluoroptic: Application Electrostatic Chuck

ESC

Service Plate

Phosphor Sensor Deposited in Cavity
Luxtron Fluoroptic: Application Wafer Backside Temp

Vacuum Sealed for Thru-Chuck Wafer Backside Temperature Measurement
Impac Pyrometers: Benefits / Advantages

- Unaffected by EMI, Microwave and RF Interferences
- Non-contact temperature measurement
- Variety of wavelength detectors optimized for specific materials
- Lens optics for small spots at remote distances
- Light pipe optics for sensing temperature in confined spaces
- 100s of Models Offered to service temp range from -50C to 3500C
- Emissivity measuring “TR” Model
Impac Pyrometers: Measure Infrared Radiation

Wavelength in microns (um)

0.4  0.7  3   6   15   1000
Impac Pyrometers: Operating Principle

Detector converts radiation into an electrical signal interpreted for temperature based on Planks Equation (next slide)

Fig. 16: Components of a pyrometer
Based on Planck's Equation for Blackbody Radiation:

\[ E(\lambda, T) = \frac{\varepsilon \cdot C_1 \lambda^{-5}}{C_2 \left( e^{\frac{C_2}{\lambda T}} - 1 \right)} \]

- \( E(\lambda, T) \) = Energy emitted, \( \text{W/(m}^2 \cdot \mu\text{m}) \)
- \( \varepsilon \) = Emissivity (1 for perfect blackbody)
- \( \lambda \) = Wavelength in \( \mu\text{m} \) (microns)
- \( T \) = Temperature \( ^\circ\text{K} \)
- \( C_1 \) = First radiation constant; \( 3.743 \times 10^8 \text{ W} \cdot \mu\text{m}^4/\text{m}^2 \)
- \( C_2 \) = Second radiation constant; \( 1.4387 \times 10^4 \mu\text{m} \cdot \text{K} \)
Impac Pyrometers: Wide range of measuring distances and spot sizes

$M_1 =$ spot size at nominal measuring distance $a_1$
$M_2 =$ spot size at measuring distance $a_2 > a_1$
$M_3 =$ spot size at measuring distance $a_3 < a_1$
$D =$ aperture (clear diameter of optics)

$$M_2 = \frac{a_2}{a_1} (M_1 + D) - D$$
$$M_3 = \frac{a_3}{a_1} (M_1 - D) + D$$

Spot sizes as small as 0.5mm at several meters distance
<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Material/Condition</th>
<th>Min Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.676 μm</td>
<td>Molten metals</td>
<td>1100°C</td>
</tr>
<tr>
<td>0.8...1.1 μm</td>
<td>Molten glass, metals, ceramics</td>
<td>600°C</td>
</tr>
<tr>
<td>0.88 μm</td>
<td>Compound Semiconductor</td>
<td>220°C w/ Model 88 Photrix</td>
</tr>
<tr>
<td>0.9 μm</td>
<td>Silicon Wafer</td>
<td>210°C w/ Model 90 Photrix</td>
</tr>
<tr>
<td>0.7...1.65 μm</td>
<td>Metals, Ceramics</td>
<td>30°C w/ Model Std Photrix</td>
</tr>
<tr>
<td>1.45...1.8 μm</td>
<td>Metals, ceramics</td>
<td>70°C w/ Model 155 Photrix</td>
</tr>
<tr>
<td>2.0...2.8 μm</td>
<td>Metals</td>
<td>50°C</td>
</tr>
<tr>
<td>3...5 μm</td>
<td>Metals, ceramics</td>
<td>5°C</td>
</tr>
<tr>
<td>3.43 μm</td>
<td>Plastic foils</td>
<td>50°C</td>
</tr>
<tr>
<td>3.9 μm</td>
<td>Flame heated furnaces</td>
<td>75°C</td>
</tr>
<tr>
<td>5.14 μm</td>
<td>Glass surfaces</td>
<td>100°C</td>
</tr>
<tr>
<td>8...14 μm</td>
<td>Non-metal surfaces</td>
<td>-40°C</td>
</tr>
<tr>
<td>8...14 μm</td>
<td>Coated metals</td>
<td>-40°C</td>
</tr>
</tbody>
</table>

Spectral radiance peak wavelengths differ by material: Pick the correct wavelength pyrometer.
Impac Pyrometers: Use Shortest Possible Wavelength

Measurement Errors with Emissivity Setting Off by 10%

- A = 8 ... 14 μm
- B = 4.5 ... 5.5 μm
- C = 2.0 ... 2.8 μm
- D = 1.45 ... 1.8 μm
- E = 0.7 ... 1.1 μm

Temp Deviation in °C

Measured Temperature in °C

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Impac Pyrometers: Use 0.94um for Silicon

Silicon emissivity over infrared spectrum

The “silicon” wavelength: 0.94 μm

Silicon is one of the most difficult materials for non-contact temperature measurements. Not only the emissivity curve strongly varies over the infrared spectrum, but each curve intensity depends on the silicon temperature. To achieve highly repeatable temperature readings, IMPAC sensors interpret 0.94 μm narrow-bandpass filter and calibrate them into the device. At this particular wavelength the emissivity of silicon is constantly high and independent of the material temperature.
Impac Pyrometers: Emissivity of non-Metals

Emissivity in %

Wavelength in µm

fire clay
Impac Pyrometers: Use 5.14um for Glass Surface

Emissivity, transmission and reflectivity in %

100 % = \( \varepsilon + \tau + \rho \)

\( \varepsilon = \) emissivity
\( \tau = \) transmission
\( \rho = \) reflectivity

Fig. 11: Emissivity, transmission and reflectivity (qualitative) of glass
Impac Pyrometers: Determining Emissivity

- Consult Material Tables
- Comparison with Contact Thermometers (e.g.: thermocouples)
- Partial Blackening of the Surface (i.e.: force the emissivity towards 1)
- Drill Material to Make Black Body (depth = 6 x diameter)
Impac Pyrometers: Ratio Pyrometers Immune to Attenuation

Temperature based on emission signal strength ratio at two different wavelengths

Fig. 17: Principle of a ratio pyrometer
Impac Pyrometers: Viewing Windows

- Crown glass (BK7) is used in pyrometers which measure in the short wavelength band (up to 2.7 μm). Crown glass is very stable, resistant to chemicals and easy to clean.

- Water-free quartz glass (Infrasil) is also used in short wavelength pyrometers (up to 3 μm).

- Calcium fluoride (CaF₂, fluorite) is used especially where glass is measured. It can be used up to 10 μm and has a high transmission coefficient.

- Germanium lenses are useful for pyrometers which measure in the long wavelength band (up to 18 μm). They have a non-reflective surface for the desired region and are opaque to visible light.
Impac Pyrometer: Application - Ingots & Substrates

Fig. 1: Polycrystalline Casting (Vacuum Melting Furnace)

Fig. 2: CVD Reactor (SIEMENS Process)

Fig. 3: Monocrystalline Silicon (Czochralski Process)
Impac Pyrometer: Photrix Lens and Light Pipe

Bent Tip Lightpipe

Fiber Optic connection between detector and collection optics (Lens or Lightpipe)
Impac Pyrometer: Photrix Configurations

- Photrix Integrated Lens Configuration
- Fiber Optics to Lens Configuration
- Photrix Direct Lightpipe Configuration
- Fiber Optics to Lightpipe Configuration
Impac Pyrometer: Application Backside Wafer Temp

Vacuum Chamber

PLASMA

Wafer

Chuck

Lightpipe
Impac Pyrometer: Application Wafer Temp Profile

Pyrometer Lens Assemblies

Transmission Cables

Quartz Window

Vacuum Chamber

Wafer

Chuck

Wafer Temperature Profile
**Impac Pyrometer: Real Time Emissivity Corrected Temp Measurement with TR Series**

- Measured Reflectance is subtracted from one to determine real time emissivity.
- Reflectance also used for deposition rate monitoring.

**LED gives** $\rho$

$\varepsilon = 1 - \rho$

**TR Series Good For:**
- MOCVD
- MBE
- CVD
Impac Pyrometer: Real Time Emissivity Corrected Temp Measurement with TR Series

Benefits

• Accurate, emissivity corrected temperature measurement
• Precise "fringe" resolution for thin film deposition monitoring

LumaSense Technologies
Innova PAS Gas Monitor: Key Attributes

- 24/7 Production Proven
- ppb and ppm level detection limits
- Dynamic range = 10000 x detection limit
- Calibrate only 1 or 2 times per year
- No Special Operator Skills Required
- Can be configured to monitor up to 5 gases
- Compatible with 200+ gases
- Rack & Bench Top Models
- Atmospheric Operating Conditions
- Industrial process application in pharmaceutical fermentation
- Can be multiplexed to monitor up to 36 sample locations
- Low sample volume of 10ml
- Cross Compensates for Interfering Gases (in IR Spectra)
1. An air sample is drawn into the measurement chamber and the chamber is sealed by the valves.

2. Radiation from the IR-source passes through a chopper and optical filter into the chamber. The IR radiation is absorbed and generates heat and pressure variations.

3. The pressure variations correspond to the chopper frequency, creating a pressure wave which can be detected by the microphones.

4. The microphone signal, proportional to the gas concentration, is post processed and the measurement result is calculated.
Innova PAS Gas Monitor: Optical Filters

26 standard optical filters covering the infrared region of interest are offered.

Each filter consist of three elements, to achieve:

- Well-defined transmission.
- Low leakage, thereby high suppression of interference.
- Not damaged by humidity.
- Complies with MIL-SC-48497A requirements.

Every system includes a filter for Water.
Innova PAS Gas Monitor: IR-Source
Innova PAS Gas Monitor: Photoacoustic Cell
Innova PAS Gas Monitor: Cross-compensation

$$SA = a_{1,A} \times c_1 + a_{2,A} \times c_2 + a_{3,A} \times c_3$$

$$SB = a_{1,B} \times c_1 + a_{2,B} \times c_2 + a_{3,B} \times c_3$$

$$SC = a_{1,C} \times c_1 + a_{2,C} \times c_2 + a_{3,C} \times c_3$$

Where:

- $SN$ is Microphone signal measuring with Filter N.
- $a_{1,N}$ is absorption of gas 1 on Filter N.
- $c_1$ is concentration of gas 1.
- $C_1$ is concentration of gas 1.
Innova PAS Gas Monitor: Select Applications

- Animal Husbandry
- Atmospheric Research
- Automotive
- Contaminated soil
- Ethylene Oxide Sterilisation
- Fermentation monitoring
- Food
- Formaldehyde
- Fuel Cells
- Gas Manufacturing
- Green House Gases
- Headspace
- Hospitals
- Indoor Air Quality

- Industrial Hygiene
- Photocatalysis
- Photographic Industry
- Power Industry
- Semiconductor
- SF6 in Transformers
- Solvent Recovery
- Thermal Comfort
- Vent Emission
- Ventilation Efficiency
- Warfare Agents