User-specific pyroelectric infrared detectors

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Content

1. Introduction
2. Single-element detectors
   2.1 Sensor design
   2.2 Sensor properties
3. Linear arrays
   3.1 Array design
   3.2 Array properties
4. Summary

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1. Introduction

- Single-element detectors and linear arrays based on LiTaO$_3$
- Applications in pyrometry, analytics, spectrometry and security techniques
- Our aims:
  - High flexibility in the detector layout
  - An as great as possible signal-to-noise ratio
  - Low microphonics
Principal functioning of a pyroelectric detector

Responsive element

Heat flow

Heat sink

\[ \Phi(t) \rightarrow \text{thermal conversion} \rightarrow T_p(t) \rightarrow \text{thermal-to-electrical conversion} \rightarrow i_p(t) \rightarrow \text{electrical conversion} \rightarrow u_s(t) \]

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Principal assembly methods of the responsive element

Silicon chip with membran
Pyroelectric thin film
Responsive element
Pyroelectric chip
Front electrode
Bonding wire
Chip glue

Variant 1
Variant 2
Variant 3

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Demands for a high signal-to-noise ratio

- Very thin responsive elements (50 µm → 20 µm → < 5 µm)
  - CMP of LiTaO$_3$
  - Ion beam etching
- High absorption coefficient of the responsive element
  - Black coatings based on Ag, Au, NiCr
  - Antireflection coatings
- Good thermal isolation of the responsive element
  - Evacuation of the package
  - Three dimensional patterning of the LiTaO$_3$ chips
2. Single-element detectors

- LiTaO$_3$ chip layouts

- Pyroelectric chip
- Responsive element
- Perforation
- Back electrode
- Front electrode

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Sensor properties

- Heat transfer in the ambient gas, $A_S = [3 \times 3]$ mm$^2$

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Sensor properties

- Heat transfer in the ambient pyroelectric material, $A_s = [1x1] \text{ mm}^2$

![Graph showing sensor properties](image)
Sensor properties

- Optimised chip layout for very thin responsive elements
3. Linear Arrays

- Fundamental structure of a pyroelectric linear array based on LiTaO₃
Array design

- Schematic sectional view and detail of a realized array
Array design

- Different layouts of array chips
Array design

SEM images of array chips with different isolation trenches

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## Array properties

- Typical properties of different linear arrays (128 Hz, $T_A = 25 \, ^\circ\text{C}$)

<table>
<thead>
<tr>
<th>Number of elements</th>
<th>1 x 128</th>
<th>1 x 128</th>
<th>1 x 128 *</th>
<th>1 x 256</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of elements $[\mu\text{m}^2]$</td>
<td>90 x 100</td>
<td>90 x 100</td>
<td>90 x 100</td>
<td>42 x 100</td>
</tr>
<tr>
<td>Pitch $[\mu\text{m}]$</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Element thickness $[\mu\text{m}]$</td>
<td>20</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Responsivity $R_V [\text{VW}^{-1}]$</td>
<td>230.000</td>
<td>550.000</td>
<td>550.000</td>
<td>620.000</td>
</tr>
<tr>
<td>Variation $R_V$</td>
<td>1...2 %</td>
<td>2...5 %</td>
<td>2...5 %</td>
<td>2...5 %</td>
</tr>
<tr>
<td>NEP $[\text{nW}]$</td>
<td>3</td>
<td>1.5</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>MTF $(R = 3 , \text{lp/mm})$</td>
<td>0.6</td>
<td>0.6</td>
<td>0.8</td>
<td>0.6</td>
</tr>
</tbody>
</table>

* - thermal isolation trenches

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Array properties

- Measured responsivity distribution of an array with stepped profil

![Diagram showing responsivity distribution]
Array properties

- Responsivity distribution of an array with a thickness of about 3 µm
Array properties

- Measured MTF of two LiTaO$_3$ arrays with 256 pixels
Array application

- Infrared line camera system PYROLINE 256

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4. Summery

- Single-element detectors with a specific detectivity
  \[ D^* (500 \text{ K}; 10 \text{ Hz}, 1 \text{ Hz}) > 10^9 \text{ cm Hz}^{1/2} \text{ W}^{-1} \]
- Sensors with very low microphonics
- Linear arrays with up to 512 responsive elements
- Minimum NEP for a 256 pixel array < 0.5 nW (128 Hz)
- MTF improvement by using thermal isolation trenches

→ Customized detectors