DOI 10.5162/irs2013/i1.1

Pyroelectric single-element detectors with very small responsive elements

V. Norkus[1], *M. Schossig*[1], *G. Gerlach*[1], *R. Köhler*[2]
[1] *Technische Universität Dresden, Solid-State Electronics Lab, 01062 Dresden, Germany*
volkmar.norkus@tu-dresden.de
Reinhard Köhler[2]
[2]*DIAS Infrared GmbH, Gostritzer Str. 63, 01217 Dresden, Germany*

Abstract

Pyroelectric detectors are used in very large numbers in devices for non-contact temperature measurement, in motion detectors and in gas analysers. Detectors with small responsive elements are necessary, in particular for the realisation of small measuring spots. On the other hand, the signal-to-noise ratio should be as large as possible.

A mathematical-physical model of the detector demonstrates that the responsivity is, in particular for low modulation frequencies, influenced by heat conduction processes into the ambient pyroelectric material and the ambient gas layer. For high responsivities it is therefore inevitable to provide good thermal insulation to the responsive element.

The article describes the principal layout and the essential properties of pyroelectric single-element detectors on the basis of lithium tantalate. The detectors have a 3D-patterned pyroelectric chip which ensures good thermal insulation of the responsive element. The self-supporting responsive element is of a few micrometres thickness. It is shown that it is possible to obtain a specific detectivity D* (500K, 10Hz, 1Hz, $\tau_W = 1$) ≥ 4 x 10^8 cmHz$^{1/2}$W^{-1} for a responsive area of [0.5 x 0.5] mm^2 with a special chip layout.

At the same time, the acceleration sensitivity of the detectors could be drastically reduced. The detector properties obtained are compared with the properties of detectors with unpatterned chips.

Key words: infrared sensor, pyroelectric single-element detector, detector properties, high D*, very low microphonics

Introduction

Pyroelectric detectors are produced in very large numbers for pyrometric applications, gas analysers, safety engineering applications and also in process control. They have a good signal-to-noise ratio, a robust construction and they are reasonably priced.

Figure 1 shows the principal function of these thermal detectors. The incident radiation flux is absorbed by the responsive element and causes a temperature change in the responsive element. Due to the pyroelectric effect this temperature change results in a change in spontaneous polarisation in the pyroelectric chip. This change in polarisation can be converted into a signal voltage u_S or a signal current using a preamplifier. In the unirradiated condition of the responsive element a noise voltage u_R can be measured at the output of the preamplifier. The noise voltage can be generated by different and mutually independent noise sources. Since all pyroelectric materials have piezoelectric properties, it is possible that also mechanical excitations of the responsive element may produce an undesired output signal u_B (microphonics).

Sensor design

Numerous applications of pyroelectric detectors are in wavelength range 1…20 µm at typical chopping frequencies of 0.1…500 Hz.

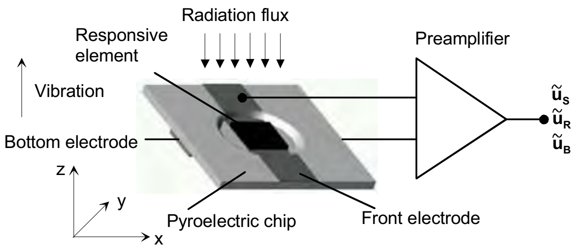

Figure 1. Principle layout and functioning of a pyroelectric infrared detector in voltage mode

Generally, all manufacturers of pyroelectric detectors strive to produce detectors with a high and spectrally homogeneous responsivity, very low noise and a minimum acceleration sensitivity. These properties can be implemented if the responsive element of the detectors shows the properties listed below [1]:

- absorption coefficient $\alpha \rightarrow 1$
- minimum thickness of the absorption layer
- minimum thickness of responsive element
- good thermal insulation
- good mechanical decoupling.

There are three basic design and assembly types of pyroelectric chips in commercial detectors:

- To ensure high efficiency and optimum material utilisation in production, the size of the responsive element is equivalent to the size of the entire pyroelectric chip (Figure 2, variant 1). Solid contact and mounting points are located on the responsive surface.
- The responsive surface is smaller than the pyroelectric chip (Figure 2, variant 2). Solid contact and mounting points are located outside of the responsive surface.
- Pyroelectric thin films are deposited on thin membranes made of silicon nitride/silicon oxide (Figure 2, variant 3). Solid contact and mounting points are located outside of the responsive surface.

Variants 1 and 3 have numerous drawbacks, in particular for the implementation of pyroelectric detectors with high signal-to-noise ratio and very small responsive area. Therefore, variant 2 was chosen to build pyroelectric detectors with very high specific detectivity, small responsive area and an acceleration sensitivity that is as small as possible, using for this purpose special technologies.

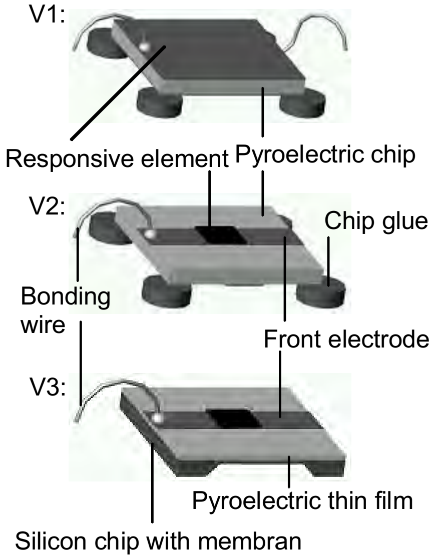

Figure 2: Design and assembly variants for pyroelectric chips in commercial detectors

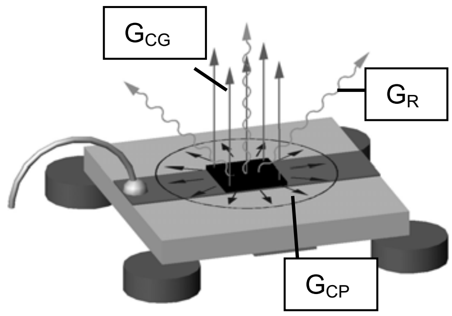

Figure 3: Heat transfer processes

Figure 3 shows that the responsive element is basically connected with its environment by three heat transfer processes [2]:

1. heat radiation G_R
2. heat conduction into the ambient pyroelectric material G_{CP}
3. thermal conduction/convection into the ambient gas layers G_{CG}.

It must be ascertained that in responsive elements with large areas (> 4 mm^2) thermal conduction into the ambient gas is basically predominant. In responsive elements with smaller areas heat loss by thermal conduction into the ambient pyroelectric material becomes predominant. Of particular importance in this process is the thermal diffusion length µ. It is defined as [3]:

$$\mu = \sqrt{\frac{2\lambda}{\omega \rho c}} \qquad (1)$$

With:

λ	heat conduction coefficent
ω	chopping frequency
ρ	density of the pyroelectric material
c	specific heat capacitance.

It becomes obvious that in particular for low modulation frequencies the heat losses into the ambient material are high.

Given the existing technical facilities at the Solid-State Electronics Laboratory, various chip layouts were developed for small-area responsive elements using variant 2. These layouts are presented in Figure 4. The designs are characterised by a new feature: a thermal insulation trench provided around the responsive element. The mechanical fastening of the responsive element and its bonding should be realised by very thin and narrow connectors.

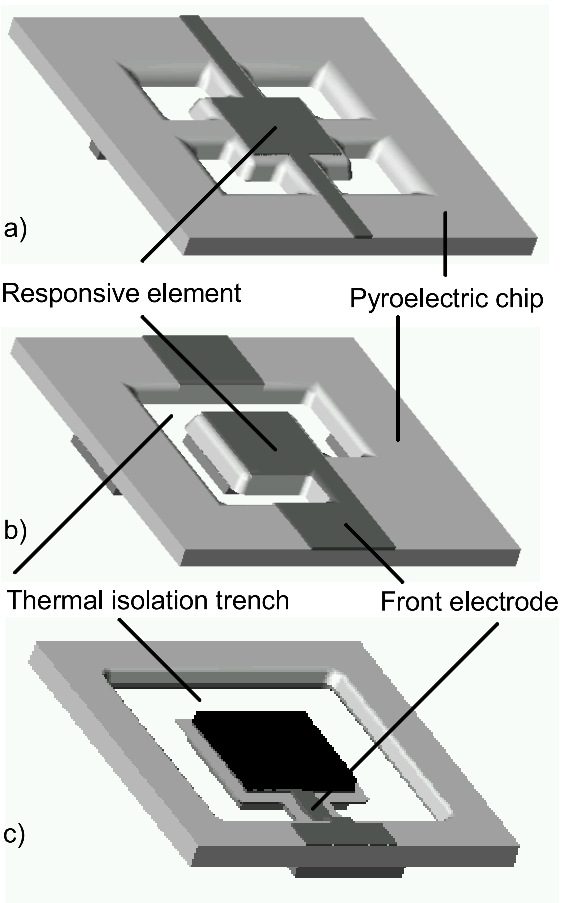

Figure 4: Various chip layouts with thermal isolation trenches

The electrical connection to the chip contact surfaces is made by thin metal films with a thickness of some 10 nm. The practical investigations undertaken aimed at the achievable detector properties, the chip yield and the mechanical stability during handling.

The sizes expected for the responsive elements were 1 mm x 1 mm and 0.5 mm x 0.5 mm. The typical thicknesses of the pyroelectric chips for detectors made by the Solid-State Electronics Laboratory on the basis of lithium tantalate are in the range 25…5 µm.

A special simulation software was used in the signal-to-noise analysis of the individual layouts. The analysis included the electrical, thermal and optical properties of the essential detector components.

The diagram in Figure 5 shows the calculated frequency dependence of the responsivity for the named element sizes and thicknesses of 5 µm with a thermal insulation trench (wt) as illustrated in Figure 4 c). It becomes obvious that the responsivity can be considerably increased by adding the trench, in particular for modulation frequencies below 10 Hz .

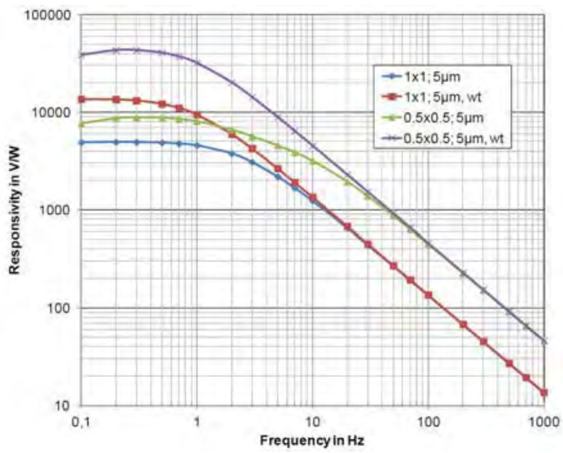

Figure 5: Calculated responsivity for A_S= 1 mm x 1mm and 0.5 mm x 0.5 mm with (wt) and without thermal insulation trench

Sensor realisation

The three-dimensional patterning of the chips is done by ion-beam etching [4]. An efficient way to manufacture the chips is their production on the wafer level (Ø 3“). Figure 6 shows images of the manufactured chips with the layout shown in Figure 4. Despite their fragile design, the chips are mechanically stable during handling and easy to assemble.

DOI 10.5162/irs2013/i1.1

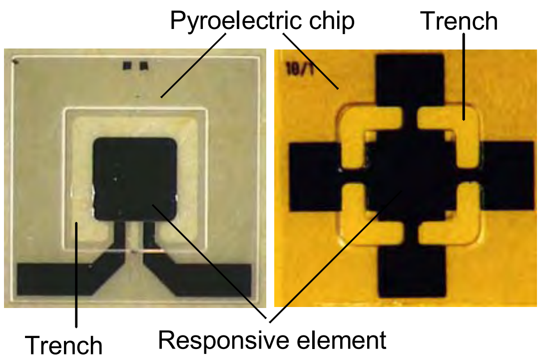

Figure 6: Patterned chips

Sensor properties

Figures 7 and 8 give the measured properties of the detectors built. It becomes clearly apparent that by providing thermal insulation trenches around the responsive element it becomes possible to manufacture small-area detectors with high signal-to-noise ratios at low modulation frequencies. At the same time the realised layout allows the acceleration sensitivity of the detector to be kept very low (Figure 9).

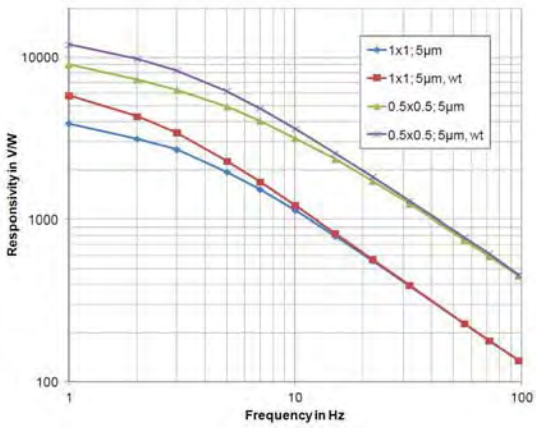

Figure 7: Measured responsivity of realised detectors

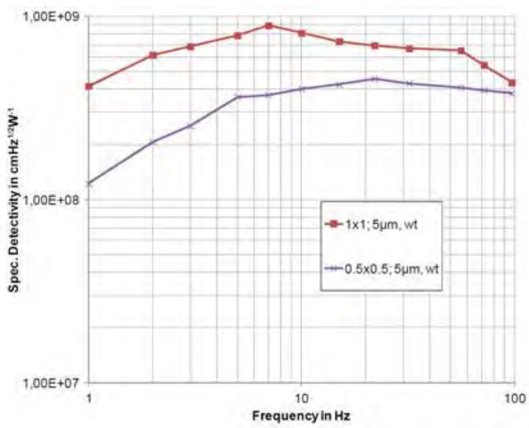

Figure 8: Measured specific detectivity of realised detectors

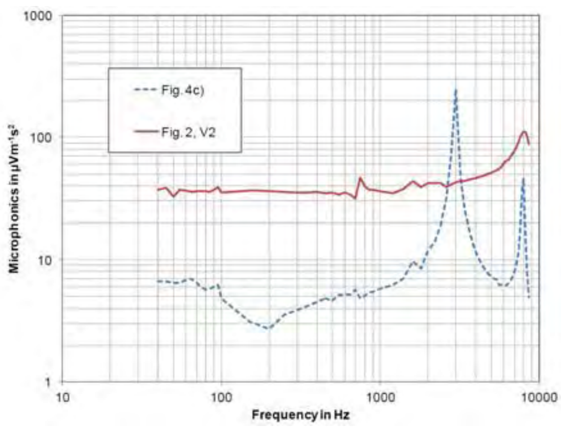

Figure 9: Measured acceleration sensitivity of realised detectors, A_S= 1 mm x 1mm

Summery

Pyroelectric infrared detectors on the basis of lithium tantalate were developed with a very small responsive area and a high signal-to-noise ratio. At the same time the chosen layout ensures very low acceleration sensitivity. It is shown that it is possible to obtain a specific detectivity D* (500K, 10Hz, 1Hz, τ_W = 1) ≥ 4 x 10^8 cmHz$^{1/2}$W^{-1} for a responsive area of [0.5 x 0.5] mm^2 with a special chip layout.

References

[1] V. Norkus, G. Gerlach, R. Köhler: A new chip layout for pyroelectric single-element detectors with high D* and very low microphonics. In: Infrared Technology and Applications XXXV. Proceedings of SPIE, Vol.7298, Orlando, 2009, 7298 2D

[2] V. Norkus, D. Shvedov, G. Gerlach, R. Köhler: Performance improvements for pyroelectric infrared detectors. In: Infrared Technology and Applications XXXII. Proceedings of SPIE, Vol. 6206 Kissimme 2006, 62062X1-11

[3] F. Lakestani, A. Salerno, A. Volcan: Modulated spot heating for measurement of thermal diffusivity. Journal of Applied Physics. 97 (2005), 013704-1,-5

[4] V. Norkus: Pyroelectric infrared detectors based on $LiTaO_3$: state of art and prospects. In: Optical Systems Design 2003. Proceedings SPIE Vol. 5251. Saint-Etienne: SPIE 2003, 121-128