A miniaturized self-calibrated pyrometer microsystem

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Summary: *This paper describes the design, modeling and optimization of a miniaturized self-calibrated pyrometer to detect infrared radiation (in 5-20 μm range of wavelengths) in order to measure the real temperature of objects without contact. The microsystem consists of a thermally insulated absorbing area and two thermopiles with the hot junctions in the absorbing area and the cold junctions on a heat sink (i.e. the silicon bulk). The complete microsystem is in silicon planar technology and each thermopile has a different reference temperature, biased by a Peltier microstructure near to the cold junction of the thermopile. A silicon die passivated with a silicon nitride membrane is the ground floor of all microsystem. The absorbing area, a black gold strip on the silicon nitride membrane is obtained by anisotropic etching of the bulk silicon from the back of the wafer. The pyrometer microsystem is composed by: the IR optical filter on the top, the electronic system built in CMOS technology added by Multi-Chip-Module (MCM) techniques and the pyrometer. Application of a network of pyrometers in textile industry is the final goal.*

Keywords: *micropyrometer, IR radiation, thermopile, Peltier effect*
Category: *1-General, Theoretical and modeling*

1 Introduction

The pyrometers are equipments of great utility, since they allow to measure temperature of an object without contact. However, the pyrometers available on the market have a limitation, since the measured value depends on the emissivity of the target object surface. Also, the existing equipment is very expensive, becoming difficult its uses in production lines that requires control of temperature in real team as dyeing in the textile industry. A new method of contactless measuring the surface temperature and/or emissivity of objects is applied based on 2 thermopiles with 2 different reference temperatures (biased by the Peltier devices). Therefore, it is possible to measure the temperature of distant objects independently of the emissivity, based on these two readings.

The voltage obtained by a sensor at T_{s1} temperature, when this is exposed to a body at a certain T temperature, is obtained by (Stefan's Law):

$$U_1 = K.\sigma\left(T^4 - T_{s1}^4\right) \qquad \text{Eq. 1.1}$$

σ - Emissivity **K – Sensor constants**

T – Target temperature **T_{s1} – Sensor 1 temperature**

If another sensor is submitted at a different temperature T_{s2}, granting that both sensors are disposed in such way that they equally receive the same amount of radiation, the voltage on this sensor is given by:

$$U_2 = K.\sigma\left(T^4 - T_{s2}^4\right) \qquad \text{Eq. 1.2}$$

The ratio between the two values is:

$$\frac{U_1}{U_2} = \frac{T^4 - T_{s1}^4}{T^4 - T_{s2}^4} \qquad \text{Eq. 1.3}$$

That equation can be arranged to:

$$T = \sqrt[4]{\frac{U_1.T_{s2}^4 - U_2.T_{s1}^4}{U_1 - U_2}} \qquad \text{Eq. 1.4}$$

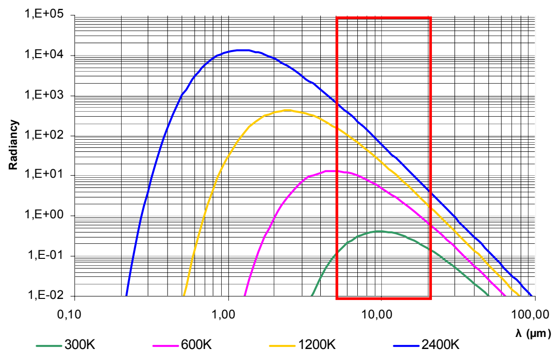

Fig. 1- Selected wavelength range.

The effect of the bandpass effect of the receiver and lens were not included in the equations (Plank's Law).

In order to get the maximum sensibility on the receiver, in the temperature between 0 ºC and 2500 ºC, based on the Plank's Law, the receiver should operate in wavelengths between 5 μm and 20 μm.

2 Simulation and design

The structure was modeled using Finite Element Analysis, in order to get the best dimensions for the Peltier converter and the Seebeck elements. These elements use a metal pair (like Nickel and Chrome) or polysilicon (type p and type n). The materials for the Seebeek thermopile are documented and compared on the references presented.

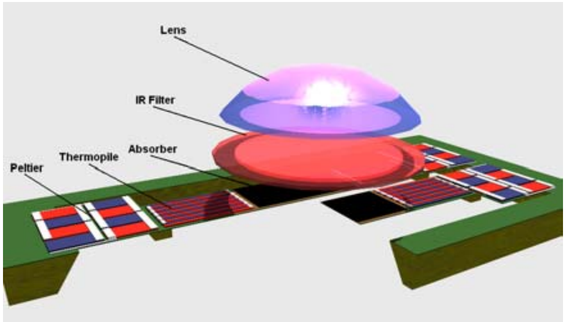

Fig. 2 - An artist impression of the complete microsystem with convex-planar lens and optical filter.

Each pyrometer can have a bandpass filter under the lens to filter a specific-wavelengths range. The compilation of the different values of the measured temperatures by a few pyrometers will compute the correct temperature of the target.

Metal	Seebeck coeff. at 273 K (µV/K)
Nickel	-18
Palladium	-9
Platinum	-4.45
Aluminum	-1.7
Lead	-0.995
Tungsten	0.13
Silver	1.38
Copper	1.70
Gold	1.79
Chrome	18.8

Table 1-The absolute Seebeck coefficient of metals.

3 Implementation

Bulk-micromachining technology in silicon (obtained through anisotropic wet chemical corrosion of the silicon wafer with an aqueous KOH solution, see Fig. 3) and deposition of thin-film layers allow to build a microsystem which integrates two thermopiles operating at two different temperatures biased by 2 Peltier structures. The silicon etching is done due to high-thermal conductivity of silicon. A silicon nitride (low-thermal conductivity) membrane is the ground-floor of the micromachined parts. A black gold strip, above the silicon nitride membrane, will absorb the IR radiation collected by a convex-planar lens including an optical filter (see Fig. 2) designed for a narrow band in the range of 5-20 µm wavelengths. This optical path eliminates the problems founded in previous research works with macroscopic pyrometers. The IR radiation absorbent area with thermal isolation and two thermopiles with the hot zone on the IR absorbent area and the cold zone on non-isolated thermal area. Each thermopile has a different reference temperature obtained through the act of a micro-structure based on Peltier effect (e.g. nickel and chromium strips) that is deposited on the cold junction of the thermopile.

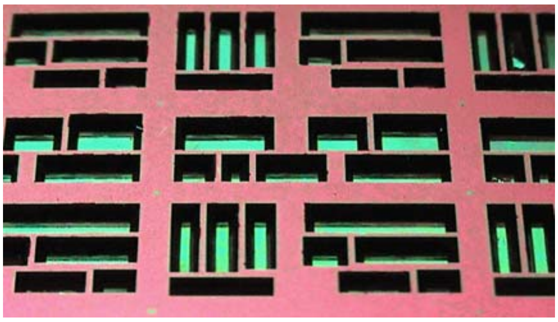

Fig. 3-The backside of a silicon wafer etched with an aqueous KOH solution. A silicon nitride membrane was used as etch-stop mask.

The electronics is merged with the micromachining parts by Multi-Chip-Module (MCM) techniques in the level of dies.

3 Conclusions

This new concept presents a miniaturized self-calibrated pyrometer microsystem with interface electronics to detect and quantify the IR radiation in the range of 5-20 µm wavelengths in order to determine the temperature of an object without physical contact. The use of a pyrometer RF network in production lines that requires control of temperature in real time as textile dyeing is the final goal of this project.

A few research has been done in order to make an RF network in 433 MHz, connecting many micro-pyrometers on a network.

References

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