

MICROPYROMETER BASED IN INFRARED METAMATERIALS LENS

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Abstract

This paper presents the design of a micropyrometer for infrared (IR) detection. The electronic parts of the micropyrometer is fabricated in CMOS technology. It is assembled together with the pyrometer subsystem, a low-loss optical lens with bandpass optical filters using multi-chip-module (MCM) techniques. The optical lens and bandpass optical filters have an inhomogeneous graded index metamaterials to simultaneously focus the light on the micropyrometer and for filtering in the desired range. The goal is to obtain a miniaturized self-calibrated micropyrometer to detect the infrared radiation in the 1-4 μm wavelength, in order to contactless measure the temperature in the range 300-2000 K.

Keywords: *Metamaterials, thermoelectric microsystem, optical lens.*

I- Introduction

The measure of the temperature, it is not always an easy procedure, specially where the simple touch of bodies is impossible. This is particularly true, when looking the example of the siderurgy industry, where the high temperatures (as is the case of the iron, whose melting point is around 1538° C) destroy the sensors. Also, the direct temperature measurement can not be easy or impossible to do, as is the case of moving parts - the rotors of electrical machines are some examples. Thus, the pyrometers revealed to be equipments of great utility, since they allow to measure the temperature of objects without the need of physical contact. However, the commercial pyrometers have a limitation, since the measured temperature depends on the emissivity of the target object surface. Also, these equipments are very expensive, thus it puts very difficulties when it is to be used in production lines that requires control of temperature, as it is the case of dyeing in the textile industry. The novelty of this micropyrometer is the use of a metamaterials lens that simultaneously filter and focus the infrared radiation to accurately measure the temperature of objects, taking the advantage of their emissivity.

II- modeling

This micropyrometer is based in a new contactless method that uses two thermopiles with two different reference temperatures, which are biased by the Peltier devices. This allows to obtain a perfect and error-free knowledge of temperatures. Therefore, with these two readings, the temperature of distant objects can be measured independently of its emissivity. Thus, considering two sensors subjected to the temperatures T_{s1} and T_{s2} [K], when these are exposed to a body at a temperature, T [K] (the temperature to be determined), in such a way that both are distributed in order to equally receive the same amount of radiation. Also, considering their output voltages, V_1 and V_2 [V] then, the temperature to be measured is given by:

$$T = \sqrt[4]{(V_1 T_{s2}^4 - V_2 T_{s1}^4) / (V_1 - V_2)} \quad (1)$$

From the Plank's law and for temperatures in the range 300-2000 K, the maximum sensitivity imposes an operation in the 1-4 μm range (the bandpass effect in the sensor was not considered).

III- IR metamaterial lens

Motivation

Optical filters for infrared in dielectric materials need a multilayer stack of two different materials with very different refractive indexes (for example, silicon dioxide, SiO_2 , and titanium dioxide, TiO_2) with more than a set of ten layers (minimum for the range of interest). Also, the thickness of each layer (accuracy with two decimal places in nanometers) is difficult to obtain by sputtering deposition. Therefore, an infrared metamaterials lens with bandpass characteristics is a outstanding solution for this type of micropyrometer devices. The loss in transmission can't be neglected, but this drawback compensates in the fabrication.

Design

The metamaterials can be designed to control electromagnetic fields in rather general ways. The concept of transformation optics, which is based on finding artificial materials that create the desired configuration of electromagnetic fields has been developed by several research teams [1]. Thus, this pushed the efforts in the last years, towards the

realization of negative index materials (NIMs) at optical frequencies. The structure of NIMs incorporates a negative electric permittivity, ϵ , resulting from an array of thin metal wires parallel to the direction of electric field and a negative magnetic permeability, μ , resulting from a pair of finite-width metal stripes separated by a dielectric layer along the direction of the incident magnetic field. The values of ϵ and μ , at a fixed wavelength of the incident light can be independently controlled by manipulating the width of the metal wires, shifting the resonance frequency of the structure and so changing the value of the refractive index $n=(\epsilon\mu)^{1/2}$ while keeping small variations in the impedance $(\mu/\epsilon)^{1/2}$ and hence in the transmission [2]. A four-layered structure in Au/dielectric/Au/glass-substrate with squared cavities of 1 μm side (Figure 1) are fabricated and assembled using multi-chip-module (MCM) techniques above the micropyrometer to meet the optical requirements in the 1-4 μm range [3].

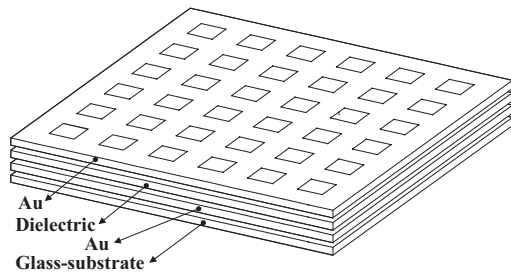


Figure 1: The metamaterials multilayer stack.

IV- Design of micropyrometer

The structure of the micropyrometer is as follows: a thermally insulated absorbing area and two thermopiles with the hot junctions placed in the absorbing area and the cold junctions on the silicon bulk acts as a heat sink. Each thermopile has a different reference temperature, which is biased by a Peltier microstructure near the cold junction of the thermopile. A silicon planar technology is used in the fabrication of the complete microsystem, whose ground floor consists on a silicon die with a passivation membrane made of silicon nitride (Si_3N_4). Also, the anisotropic etching of the bulk silicon from the back of wafer is used to obtain the absorbing area, which consists on a black gold strip on the silicon nitride membrane.

Figure 2 shows an artist impression of the proposed micropyrometer, where for each pyrometer a metamaterials lens with bandpass characteristics must be designed to simultaneously focus the radiation and for filtering the spectrum, let passing the infrared radiation in the 1-4 μm range.

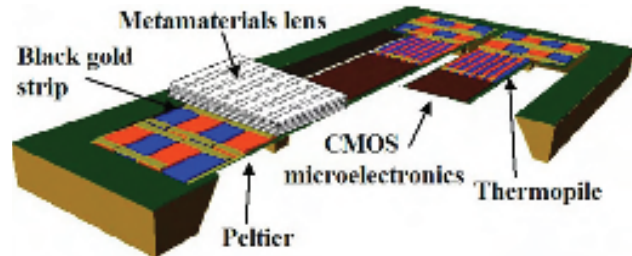


Figure 2: An artist impression of the complete microsystem with a lens made of metamaterials to simultaneously focus and filtering the radiation in the desired infrared range.

V- Conclusion

A new concept for a miniaturized self-calibrated pyrometer microsystem was presented in this paper. The pyrometer is assembled with the interface electronics to detect and to quantify the amount of infrared radiation in order to measure the temperature of an object without the need of contact. The goal of this micropyrometer is measuring the temperature in production lines that requires its control in real-time. The innovation deals with the design and fabrication of a low-loss lens and optical filter in metamaterials for infrared radiation in the 1-4 μm range.

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