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Research note

Objects cloaking in LWIR region by using a high efficiency infrared pixel

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Abstract

This article, introduces a new pixel which can emit infrared wavelengths from its surface and can be used for the purpose of cloaking objects from thermal cameras. This pixel can simulate the temperatures between 0 and 100ºC emited from an infrared radiation in LWIR (8-12 micrometres) region. Nanocomposite material is used in the pixel structure and this has increased its capacities like ZT factor %40-50 better than the commercial material like Bi_2Te_3. Technical aspects of the pixel such as the emission wavelengths, rate of temperature changing, thermal contrast, ZT factor and so on are discussed in this paper and were determined by using thermography, non-contact thermometry, radiometry, four probe ac method and temperature differential.

Keywords: infrared, pixel, cloak, nanocomposite, LWIR

1. Introduction

Infrared region is one of the most important parts of electromagnetic spectrum. Detection and imaging of Infrared Radiation (IR) are of great important to a variety of military and civilian applications ranging from night vision to environmental monitoring, biomedical diagnostics, remote sensing, and thermal probing of active microelectronic devices. In particular, the wavelength region from 8 to 14 μm is of importance, because the atmospheric absorption in this region is especially low and this region contains the peak of the blackbody spectrum for objects around the room temperature [1-4]. A blackbody absorbs all radiation striking its surface. If it is at constant temperature, but thermally isolated from its surroundings, it must emit the same amount of energy that it absorbs. Hence, a blackbody is a perfect emitter as well as a perfect absorber. A real object that you might observe with an infrared sensor is not a blackbody, but its behaviour is often qualitatively similar to that of a blackbody. The spectral distribution and magnitude of an object's radiation are primarily a function of the object's temperature and emissivity.

Terrestrial objects like human, tank, truck, building and etc emit infrared radiation in LWIR region. Higher object temperature like missiles, jet exhaust and airborne with temperature above 300°C emit radiation in MWIR and lower wavelengths. MWIR and LWIR bands may mean slightly different spectral regions however; the majority of I2R sensor engineers use the convention above. One can quickly determine that a high I2R target-to-background contrast requires either high-temperature differential, emissivity differential, or a combination of both [5].

The thermoelectric efficiency of a material is quantified by a figure of merit (Z), which contains three physical quantities:

- Seebeck coefficient (S)
- electrical conductivity (σ)
- thermal conductivity (k)

The first two quantities need to be as big as possible, while the last one needs to be small to be able to maintain the temperature difference between the hot and cold side. The problem is that all three quantities are related, and cannot be optimized independently. It turns out that semiconductors provide the best compromise with commercially used refrigeration materials, such as Bi_2Te_3 having figures of merit:

$$ZT = \frac{S^2 \sigma T}{k} = 1, \tag{1}$$

here T is the absolute temperature, and the other parameters were defined above. There is no fundamental upper limit on ZT, but for decades it was limited to

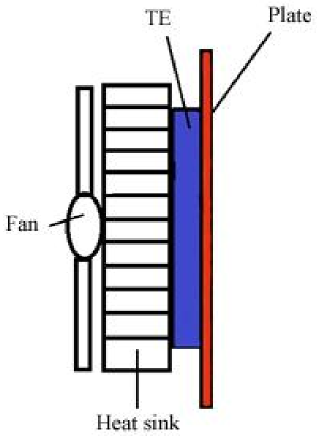

Figure 1. Components of infrared wavelengths emitter pixel.

values around one. The bigger the value of ZT, the greater the energy conversion efficiency of the material [6].

A great deal of research has focused on improving the Thermo Electric (TE) properties of Bi_2Te_3 materials [7-13]. Nanostructure can enhance the electronic density of states near Fermi level, and the nanostructured thermoelectric materials have a large number of boundaries that will strongly scatter the phonons and carries [14].

High performance fabricated thermoelectric and other components are used to design and construct a high performance pixel to emit infrared radiation in this report. Thermal screen can camouflage and deceptionour object in LWIR wavelengths by playing infrared pattern on its surface, using this pixel. The commercial thermoelectrics are slow against voltage change and are not comfortable for being used in thermal screen because they need high speed pixels for changing the simulate temperatures and this article introduce a new high response pixel.

2. Experimental

Spark Plasma Sintering (SPS) was used for fabricating Graphene/Bi_2Te_3 nanocomposite thermoelectric bulk material; and the figure of merit parameters were measured by four probe ac method and the temperature differential with a Seebeck coefficient / electric resistance measurement system ZEM-3. Fabricated thermoelectric was biased among cooper sheets and was joined to a high thermal conductive plate that is illustrated in figure 1.

As can be seen, the pixel consists of four main parts: plate, thermoelectric, heat-sink and fan. The plate is used to extract the emission surface and is made from graphene which has good thermal conductivity. When the thermoelectric is biased among direct DC voltage, the heat moves from the thermoelectric to the plate and vice versa, with change in bias direction. Because the changing temperature for simulating and emitting different wavelengths is important, the heat sink and cooling system were used for emitting longer wavelengths. The arrays of these pixels create a thermal screen that can show an infrared pattern in LWIR region.

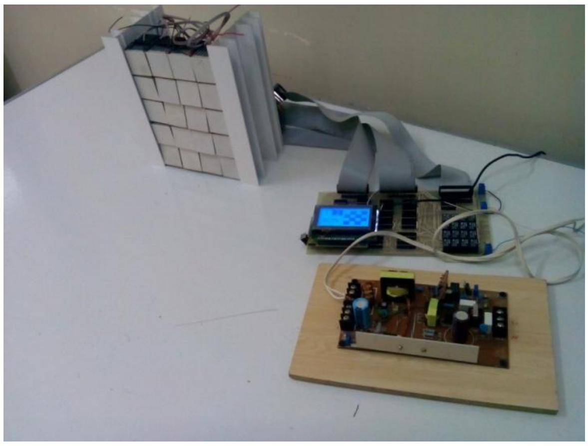

Figure 2. Infrared screen which is made from fabricated pixels.

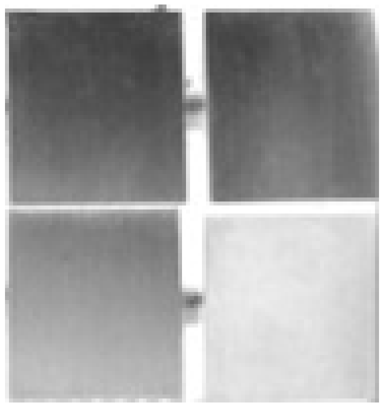

Figure 3. LWIR thermograph of infrared screen with four neighbour pixels.

Figure 2 shows an infrared screen that is fabricated with these infrared pixels.

As can be seen in figure 2, the screen electronics contain a micro controlling and power supply system which can supply and control each pixel independently. A switching power supply has been designed to have a high gain and low loss. A switching technique is also used to deliver zero and VCC voltages to the infrared screen to cool and heat the pixels. With this method, each pixel has a different temperature and thermal contrast. Figure 3 shows the thermal contrast in the part of infrared screen.

As can be seen in figure 3, each pixel works separately, has different temperatures from neighbour pixel and thermal contrast was obtained. The plate coated with a ferrite layer increases emissivity coefficient like a blackbody ($\varepsilon(\lambda) = 1$) and also absorbs microwave wavelengths for protecting against microwave wavelengths. The reliability of pixel was tested with radiometry and thermometry. The thermal speed, required voltage for producing LWIR wavelengths and emitting wavelengths, was determined.

3. Results and discussion

The figure of merit ZT for fabricated thermoelectric and commercial Bi_2Te_3 is illustrated in figure 4. As can be shown, the figure of merit ZT for fabricated sample is %40-50 smaller than commercial thermoelectric and this parameter has a direct influence on the pixel efficiencies

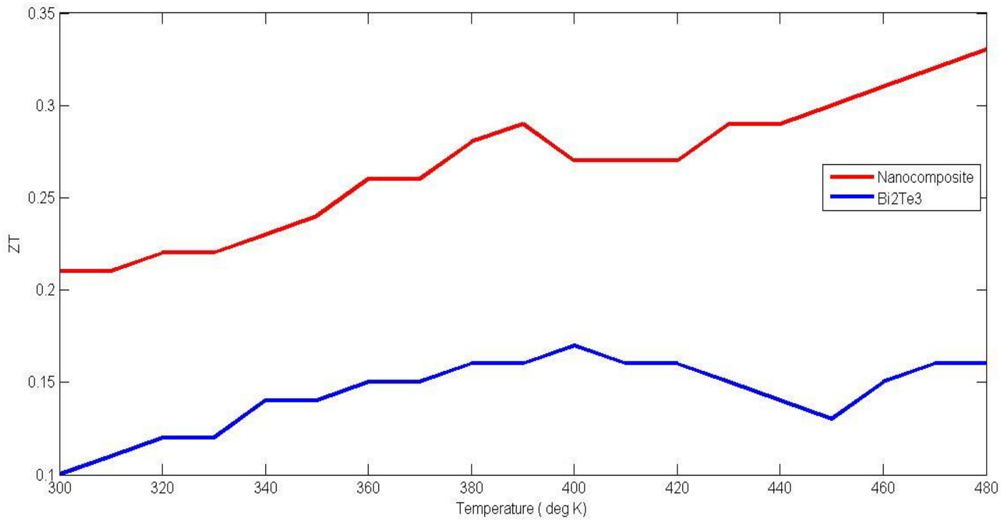

Figure 4. Diagram of merit ZT for the fabricated and commercial thermoelectric.

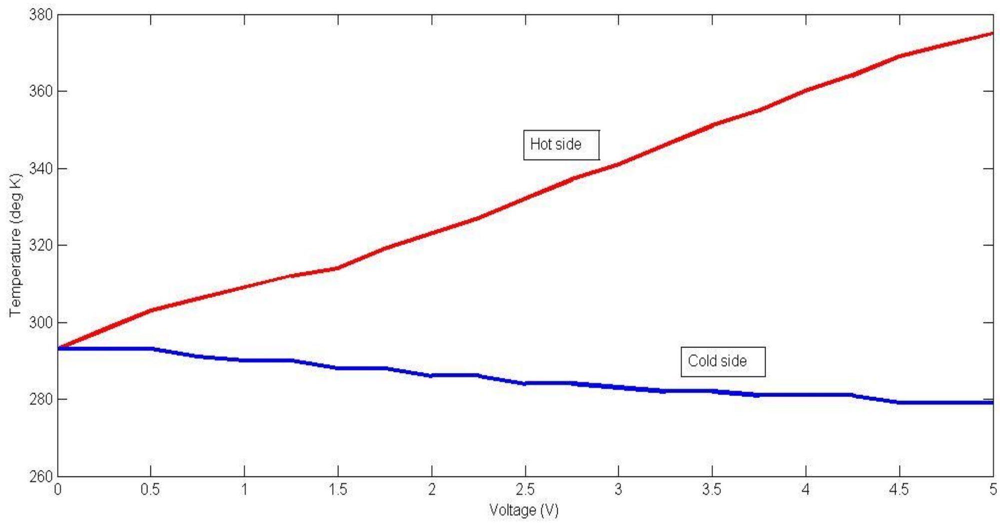

Figure 5. Plate temperature versus voltage.

such as the speed of changing the wavelength of and the pixel power consumption.

The maximum power for commercial is $6\,A\times 12\,\text{V} = 72\,\text{Watt}$, but the fabricated pixel maximum power is $9/17\,A\times 8\text{V} = 4.2\text{Watt}$. For calculating the total power, we should cross this power to the pixels number. It is imperative to note that, we did not need all pixels in each pattern and some of them are turned off. With applying 0-5 biasing forward and backward voltage, the pixel's temperature changed from the room temperature to the desired temperature.

Figure 5 illustrates temperature variations of the inner and outer of a pixel with respect to the voltage values between 0 and 5 volts. As can be seen, the temperature of the exterior surface (hot surface) in 5 volts forward bias is about 100 °C and the temperature of the inter surface (cold surface) is 5°C, so the resulting temperature difference (ΔT) using this pixel is about 95°C. This figure is plotted without fan and heat sink when they were used. This figure changed specially in cold side because the fan and heat sink removes the heat faster than now. With a radiometry measurement system, emission wavelengths versus applying voltage of one pixel are obtained, temperature of pixel increases and infrared emitted spectrum is shifted to shorter wavelengths and the outer side of the pixel was cooled and emitted longer wavelengths by backward voltage.

The speed of changing wavelengths emission is a very important factor for infrared pixels. Figure 6 shows the speed of changing the temperature versus time that is measured with a thermometer for fabricated and commercial thermoelectric and is obtained with a +5 volts constant DC forward bias. As shown in figure 6, in the positive bias, the speed of commercial thermoelectric is about 12°C per second while for fabricated thermoelectric it is about 16°C per second. This figure shows that the speed of fabricated thermoelectric is about %30 greater than commercial.

But it should be noted that this treatment was different in other temperatures. This speed is different

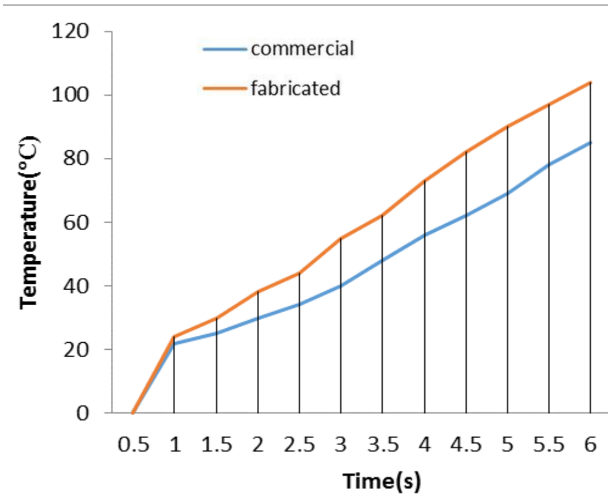

Figure 6. Time-temperature diagram in forward bias for fabricated pixel.

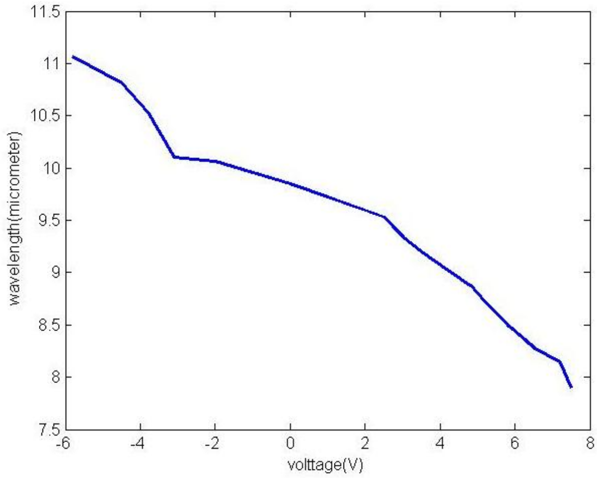

Figure 7. Voltage-wavelength diagram for fabricated pixel.

from forward bias and is about 1.42 and 1.1°C per second for fabricated and commercial respectively and this is different when the pixels work in different environmental conditions; also on thermal screen, many patterns with different temperature contrasts were required. When a pixel has a high temperature in one pattern and when we need to change its temperature to a colder one, this process and its speed are different with changing temperature from room to higher degrees. By applying a higher voltage, we can recoup the lost time. The speed of changing the emission of wavelengths depends on the voltage value and forward or backward biases. The speed of changing wavelength in the forward bias is greater than the backward one. Decreasing the temperature is a function of the environment temperature, voltage bias, fan speed and heat sink conductivity. Aluminium heat-sink is comfortable because it has a good conductivity and is light too.

Figure 7 is calculated from Planck's law and shows that pixel emits the wavelengths between 7.5 to 11.5 that contain objects with temperature between about zero to 100 °C.

4. Conclusions

The fabricated pixel with nanocomposite thermoelectric is faster than Bi_2Te_3 thermoelectric and its speed is about %30-40 greater than Bi_2Te_3 thermoelectric. The infrared screen is suitable for displaying infrared scenario which their temperatures are between 0 and 100 °C. This pixel with 64 cm^2 coverage area has about 30 grams weight and is suitable for army vehicles cloaking. Factors that should be considered are: changing the pattern speed, total weight, thickness plane, exterior plane shape, power supply, and noise protection.

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