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120 × 90 element thermoelectric infrared focal plane array with precisely patterned Au-black absorber

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Abstract

This paper presents a 120 × 90 element thermoelectric infrared focal plane array with a precisely patterned Au-black absorber that provides high responsivity and a low cost potential. The device has a responsivity of 3900 V/W. The overall chip size is 14.4 mm × 11.0 mm with a 12.0 mm × 9.0 mm imaging area. Each detector consists of two pairs of p–n polysilicon thermocouples and has external dimensions of 100 μm × 100 μm and internal electrical resistance of 90 kΩ. The precisely patterned Au-black infrared absorbing layer was achieved by both a low-pressure vapor deposition technique and a lift-off technique utilizing a PSG sacrificial layer. These techniques make it possible to obtain a Au-black pattern with the same degree of accuracy as with the CMOS process. The Au-black layer showed high absorptance of more than 90% to the light source with a wavelength of from 8 to 13 μm. This performance is suitable for automotive applications as well as consumer electronics.

Keywords: Infrared; Sensors; Thermoelectric; Vehicles; Au-black

1. Introduction

An infrared focal plane array (FPA) operating at a wavelength of 10 μm is a promising device for automotive sensor systems because it can detect a human body both day and night without any light source, measure temperature, and easily distinguish a human body from the background. Since infrared radiation emitted from the human body have less energy than visible light, semiconductor sensors made of expensive materials such as HgCdTe traditionally needed to be cooled to cryogenic temperature, and the influence of thermal noise had to be eliminated. It has been difficult to apply these infrared detectors to vehicles because of such factors as the cooling system price and size.

However, high-performance uncooled infrared imagers have been put to practical use through the further development of semiconductor technology in the U.S. [1,2]. As a result, performance virtually equal to that of cooled devices has been achieved these days. A nighttime vision enhancement system incorporating uncooled infrared imagers has attracted much attention since it was first implemented on ordinary passenger cars in 1999. The infrared imagers of this system use ferroelectric phase transition materials and adopt a hybrid structure, making it necessary to adjust the temperature accurately near the phase transition temperature and to modulate the incident light with an optical chopper. Therefore, even uncooled infrared imagers [1–5] having fewer parts than the cooled type are still expensive and their automotive use is limited to luxury vehicles at present. In order to promote widespread use of uncooled infrared imagers on mass-produced vehicles, further cost reductions are necessary.

We have been developing a low-cost thermoelectric infrared FPA [6–9] with a structure and materials compatible with the ordinary CMOS process. As part of the development program, we participated in the first and second phases of the Advanced Safety Vehicle (ASV) program promoted by the Japanese Ministry of Land, Infrastructure and Transport from 1991 to 2000. That work has led to the development of a nighttime pedestrian warning system [10] and a blind spot pedestrian warning system using infrared imagers [11].

This paper first presents the device structure and a performance simulation of a prototype sensor. It then describes the fabrication process and the configuration of the 120 × 90

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element FPA. Finally, it describes the measured performance data of the FPA.

2. Device structure

Thermoelectric infrared sensor (thermopile) responsivity R is given by

$$R = n\alpha R_{th} A_b A_r \tag{1}$$

where n is the number of thermocouple pairs, α the Seebeck coefficient, R_{th} the thermal resistance between the hot and cold junctions, A_b the infrared radiation absorptivity, and A_r is the fill factor.

To improve thermopile responsivity, it is generally necessary to increase the number of thermopile pairs n. Since increasing n could cause a reduction of thermal resistance R_{th}, the influence of n on responsivity R had to be examined in detail. As shown in Fig. 1, in the case of atmospheric pressure-sealed thermopiles currently on the market, the thermal resistance between the hot and cold junctions R_{th} equals the parallel connection of the thermal resistance of the membrane $R_{th(membrane)}$ and the thermal resistance of the filling gas $R_{th(gas)}$. In this case, the maximum value of R_{th} is smaller than $R_{th(gas)}$. Therefore, improving the thermopile responsivity of atmospheric pressure-sealed thermopiles requires an increase in the number of pairs, not in R_{th}. Increasing the number of pairs, however, causes greater electrical resistance R_{ele} in the thermopiles, resulting in higher Johnson noise. On the other hand, in the case of vacuum-sealed sensors, the thermal resistance between the hot and cold junctions R_{th} almost equals $R_{th(membrane)}$ because of very large $R_{th(gas)}$. Large $R_{th(membrane)}$ and small n yield high responsivity and small R_{ele} at the same time. R_{ele} can achieve low Johnson noise and a high signal-to-noise ratio. To increase $R_{th(membrane)}$, two folded beams were adopted instead of the four beams used previously. This structure achieves both the desired fill factor and beam length. The dimensions of the device are explained below.

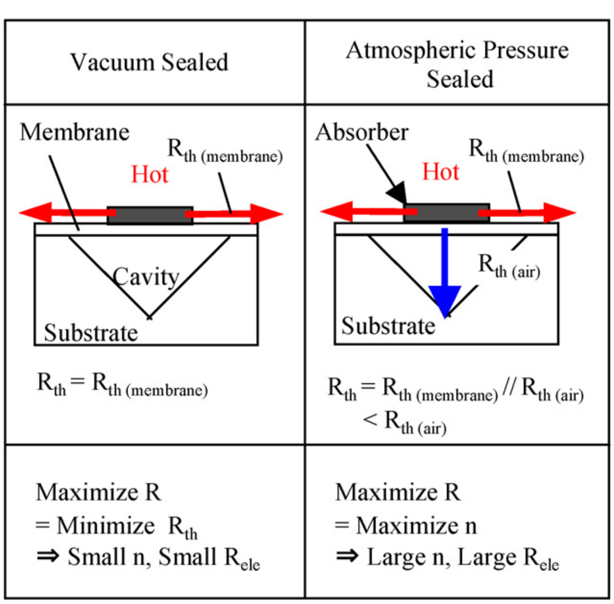

Fig. 1. The design concept of a vacuum-sealed sensor.

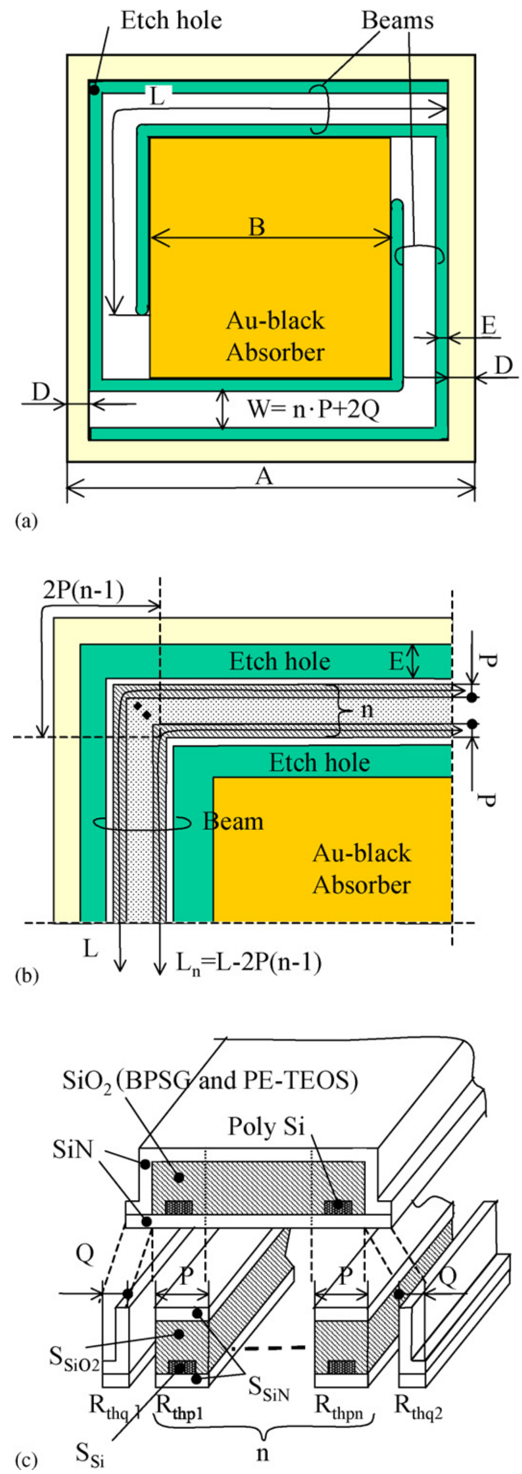

Fig. 2. Schematic diagram for calculation of responsivity: (a) beam layout; (b) beam length calculation; (c) a cross section of the beam.

In this case, n lines of polysilicon are laid out on each beam as shown in Fig. 2(a) and (b). The beam width W and the size of the infrared absorber B are given by

$$W = nP + 2Q \tag{2}$$