IR Thermal Imaging Device using Photo-Patternable Temperature Sensitive Paint

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Abstract. This paper reports an infrared-to-visible transducer array made of temperature sensitive paint (TSP) for low-cost thermal imaging application. A novel fabrication process using a photo-patternable temperature sensitive paint (PTSP) combined with an SU-8 transfer method was developed. The developed process is simpler than before, and prevents the TSP structure from plasma-induced damage and sticking across a sacrificially-etched gap. The self-suspended structure as small as 100 μm was successfully fabricated with a large gap of 40 μm from the substrate. The heated object of 300°C was detected with a resolution of about 0.4 mm.

1. Introduction
An infrared (IR) sensor array is widely used for a non-contact thermal imaging such as disease survey in airports, failure analysis of electric components and scientific experiments. Nowadays, some consumer applications of the IR sensor array such as home security, human activity monitoring and precise fire detection have been proposed, and a low cost sensor array is required. Various types of IR sensors have been developed, including a bolometer [1], a thermopile [2], a pyroelectric [3] and a mechanical types [4]. However, the bolometer and pyroelectric sensor array require complicated structures made of non-CMOS-compatible materials on a read-out LSI, which increases the fabrication cost. On the other hand, the thermopile array is one of the promising low-cost devices, but it needs a large in-plane thermal isolation structure, which limits the spatial resolution. Anyway, a large array of thermopiles also need sensor fabrication on a read-out LSI.

Recently, an array of IR-to-visible transducers was proposed as the low-cost thermal imaging device [5, 6]. Figure 1 shows the working mechanism of the device. A thin film made of a temperature sensitive paint (TSP) and an IR absorber is suspended by a thermal isolation structure. The TSP, which has been used as a temperature sensor in a wind tunnel experiment [7] and a micro channel evaluation [8], emits the visible luminescence whose intensity decreases with temperature [9]. The thermally isolated TSP thin film is heated by IR light radiated from the observation object, thus the incident IR power can be converted to the intensity of visible light, which can be observed by a CCD/CMOS camera. The optical read-out method used here does not need any electric wirings, which promises high thermal isolation of each pixel and makes it scalable to large pixel numbers.
The previous reported IR-to-visible transducer was made by using reactive ion etching (RIE) for the micro-patterning of the TSP [6]. However, RIE sometimes caused plasma-induced damage in the TSP, which degrades the sensitivity. In addition, a thick sacrificial layer was required to prevent the self-suspended structure from sticking to a substrate, leading to severe control and long deposition time. To solve these problems, we propose a new fabrication process using a photo-patternable TSP (PTSP) combined with an SU-8 transfer method to make a large-gap self-suspended structure without a thick sacrificial layer.

2. IR-to-visible transducer using PTSP

2.1. Structure of the device

Figure 2 shows the structure of the device. The sensing part is made of the PTSP, a reflector and an IR absorber. The thermal isolation supporting structure consists of PTSP narrow beams and SU-8 long posts. The high-aspect-ratio SU-8 structure enables the self-suspended structure separated far away from the substrate, which prevents the structure from sticking. A glass was used as the substrate to transmit both excitation UV light and visible luminescence.

2.2. Photo-patternable temperature sensitive paint

The conventional TSP consists of a luminescent material such as Eu(TTA)$_3$, a polymer binder such as PVB or PMMA and a solvent such as MEK or IPA. To add a photo-patternability to the TSP, we use SU-8 as the polymer binder and the solvent [10]. The composition of the PTSP was 0.03 g of
Eu(TTA)₃ and 1.0 mL of SU-8 5. The temperature sensitivity at the room temperature was about – 0.3%/K.

2.3. Fabrication

Figure 3 shows the fabrication process. First of all, the Ge thin film, which was used as the sacrificial material, was deposited on a temporary glass substrate and partially etched to make a mold for the IR absorber. A black-body paint (JSC-3, Japan sensor Co., Ltd., Japan) mixed with SU-8 5 was spread into the mold. After planarization, an Al thin film was deposited and patterned. The PTSP and SU-8 3050 were patterned by photolithography. Another glass substrate for a device was covered with SU-8 5 without UV exposure. Both temporary and device wafers were aligned and heated at 95°C for bonding using the unexposed SU-8 as a bonding material. Finally, the Ge sacrificial layer was etched by XeF₂ and the temporary glass substrate was separated.

Figure 3. Fabrication process.

Figure 4 shows the scanning electron micrograph of the device. The size of each sensing element was 100 μm. The distance between the self-suspended structure and the substrate was as high as 40 μm.

Figure 4. SEM of the self-suspended IR-to-visible transducers.
3. Thermal imaging

Figure 5 shows an experimental setup for the thermal imaging. The fabricated IR-to-visible transducer array was placed in a vacuum chamber to enhance the thermal isolation of each element. A Ge objective lens and a glass window were placed on both sides of the chamber. The PTSP was excited by UV-LEDs (NS355L-5RLO, Nitride Semiconductors Co., Ltd., Japan), and the luminescence was observed by the CCD camera (BU-50LN, Bitran Corp., Japan) through an optical band-pass filter. All the optical components were placed in a black box to eliminate the ambient light. A ceramic heater shown in Fig. 6 was used as an observation object. A K-type thermocouple was attached to the heater using ceramic glue to measure the real temperature.

Figure 5. Experimental setup.

Figure 7 shows a captured luminescence. The temperature rise of the sensing element, $\Delta T(x, y)$, at the point $(x, y)$ was calculated as

$$\Delta T(x, y) = S^{-1} \left( \frac{I(x, y) - I_0(x, y)}{I_0(x, y)} \right),$$

where $S$, $I$ and $I_0$ are the sensitivity of PTSP, the intensity of luminescence with and without IR irradiation, respectively [11].

Figure 6. Ceramic heater (observation object).

Figure 7. Luminescence from the device.
Figure 8 shows the obtained thermal images of the heater at different locations. The temperature of the heater was kept at 700°C. The value indicated in Fig. 8 was the temperature rise of the sensing element calculated by Eq. (1). The shape of the heater with a ceramic glue (Fig. 6) was clearly observed. The resolution of the thermal image was as small as about 0.4 mm. The thermal time constant of the sensing element was measured about 2 s. The minimum detectable temperature was as high as 300°C due to not-yet-optimized process and structure.

4. Conclusion
An IR-to-visible transducer array using photo-patternable temperature sensitive paint was developed for low-cost IR imaging. A transfer method was employed to fabricate a large-gap self-suspended structure without an ultra-thick sacrificial layer. The self-suspended structure with 100 μm square pixel was fabricated with a gap as high as 40 μm. The thermal image was successfully observed. The obtained resolution, thermal response time and minimum detectable temperature were about 0.4 mm, 2 s and 300°C, respectively.

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