RADIAL TYPE MICRO THERMOELECTRIC DEVICE FOR LED CHIP COOLING

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Abstract: We developed the micro thermoelectric cooler (μTEC) for application in LED cooling. In the proposed μTEC, thermoelectric legs were placed in radial direction and linked in series electrically. Heat transfer occurs in radial direction, and active cooling of the LED is carried out. The fabrication process of the radial type μTEC is simple because all the metal interconnects are processed in one step. In addition, the longer length of thermoelectric legs is easily implemented. In this paper, the proposed μTEC is fabricated by the stencil lithography with co-sputtering. The characterization of the proposed μTEC is done to show the feasibility for application in LED chip cooling.

Keywords: LED, Thermoelectric, Stencil lithography, Radial type, Peltier cooler

INTRODUCTION

With the ever-increasing combination of higher heat flux with higher package density in high-power LEDs, providing sufficient heat dissipation from the LED package module is becoming increasingly challenging, which makes active cooling of LED more important [1]. Figure 1(a) shows the conventional integration of μTEC (micro thermoelectric cooler) in LED package module. In this case, μTEC is apart from LED junction site. Therefore, its efficiency of controlling the LED junction temperature goes down. Figure 1(b) shows the proposed integration of micro thermoelectric cooler in LED package module. μTEC is placed on the just near side of LED junction site. Both μTEC and LED are in the encapsulant. Therefore, the junction temperature of LED comes down effectively. Compared to the vertical type μTEC [2], the fabrication process of the radial type μTEC is simpler than that of the vertical type μTEC because all the metal interconnects are processed in one step. In addition, the longer length of thermoelectric legs is easily implemented.

Major difficulties of the fabrication of μTEC are in the patterning techniques on the thermoelectric legs, the lift-off method with SU-8 photoresist [3] has the temperature limit due to the maximum working temperature of SU-8 photoresist. The thermoelectric properties of the thin films are worse than those obtained in bulk materials. To avoid the temperature limits on film deposition, the thermoelectric legs are patterned with the wet-etching technique [4]. However, the influence of the etchant composition in the etch rate and pattern quality must be investigated because it involves the hazardous acids in the process.

In the present work, the thermoelectric legs are fabricated by the stencil lithography. The stencil lithography provides high substrate temperature required to fabricate high-quality thermoelectric films. For the good step coverage of the thermoelectric legs, the shadow mask needs to be very thin. The major components of the proposed μTEC are p-type Bi-Sb-Te and n-type Bi-Te thin films.

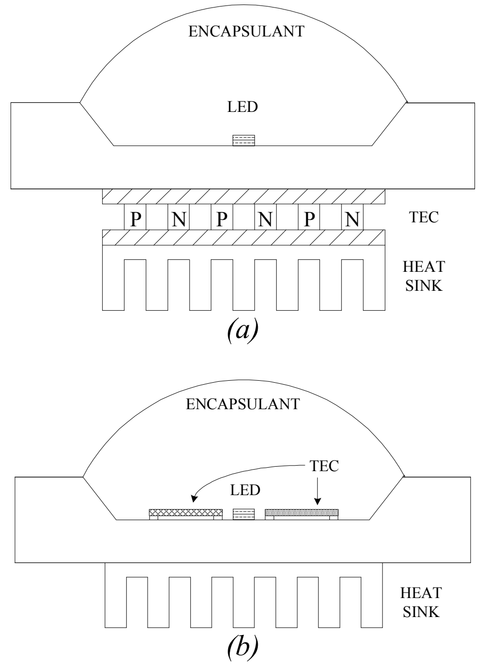


Fig. 1: μTEC in LED package module: (a) conventional integration, (b) proposed integration.

DESIGN & FABRICATION

Figure 2 shows the drawing of the proposed μTEC. In the proposed μTEC, thermoelectric legs were placed in radial direction and linked in series electrically. Heat transfer occurs in radial direction, and active cooling of the LED is carried out.

Figure 3-1 shows the fabrication process of thermoelectric devices. The major fabrication process steps entail the lift-off process for the metal interconnects and the stencil lithography for the thermoelectric film deposition. The 4 inch silicon wafer was used for the device fabrication. To provide electrical insulation, about 300 nm silicon dioxide layer was grown on the silicon wafer. After thermal oxidation of silicon dioxide, O_2 plasma cleaning was done for 5 minutes. The metal interconnects was fabricated by the lift-off method. AZ5214 PR was chosen as sacrificial layer because it can be used as both positive and negative mode. PR was spin-coated at 1500 rpm to make 2.5 µm thickness, soft-baked at 100℃ for 180 sec, exposed at 120 mJ/cm^2 for 24 sec and developed by AZ500MIF. Then Cr/Au/Ni layers are deposited by sputter. The Cr, Au and Ni are 30 nm, 200 nm and 200 nm thick, respectively. Ni was used to prevent the diffusion of Au. The rest of sacrificial layer was washed out together with the deposited layers covering it by acetone.

For the thermoelectric property enhancement and the simple fabrication process, the thermoelectric element was fabricated by stencil lithography. In the stencil lithography, the limitations involved by PR can be overcome because PR was not used and the patterned thin film is made in a single process step. In this stencil lithography, the silicon shadow mask was thinned to 300 µm by CMP process and patterned by DRIE as shown in Figure 3-2. The silicon shadow mask was aligned with the previously made electrode pattern by the custom-made aligner in Figure 4. When sputtering, the target-substrate distance was 35 cm and substrate holder was heated and rotated. Titanium was sputtered as an adhesion layer and then the thermoelectric film was deposited. Co-sputtered thermoelectric film thickness was about 4.0 µm. The major components of the proposed TEC are p-type Bi-Sb-Te and n-type Bi-Te thin films.

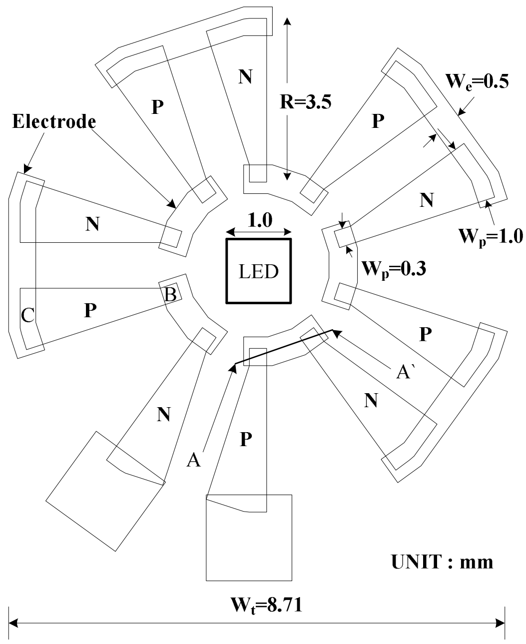


Fig. 2: The diagram of the proposed µTEC

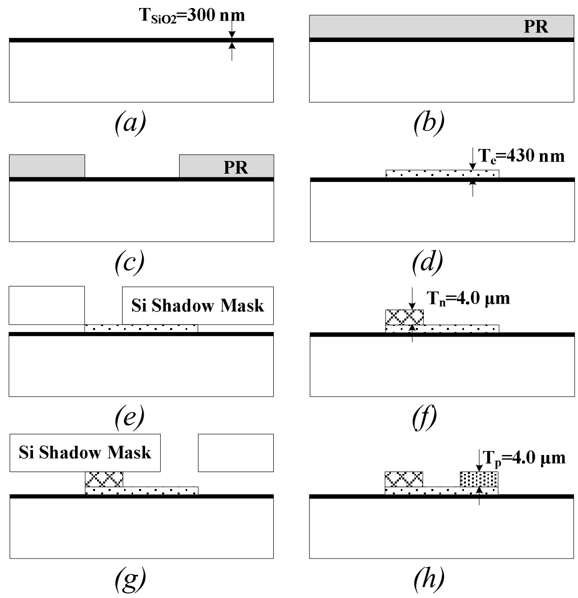


Fig. 3-1: The fabrication process of µTEC for the cross section A-A' in Fig. 2 : (a)Thermal oxidation, (b) PR coating, (c) PR patterning,(d) Electrode deposition, (e)(f) N type deposition and (g)(h) P type deposition.

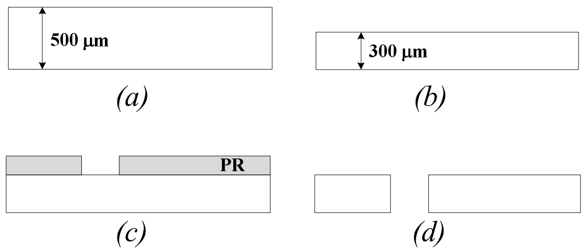


Fig. 3-2: The fabrication process of silicon shadow mask: (a) Bare silicon wafer, (b) CMP, (c) PR patterning, (d) DRIE.

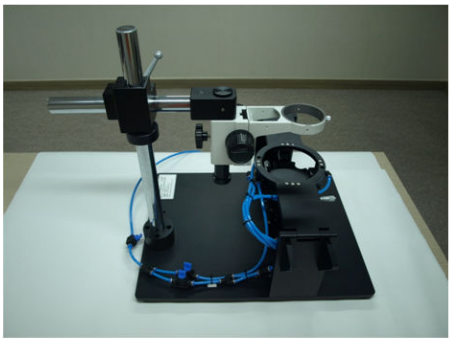


Fig. 4: The custom-made mask aligner

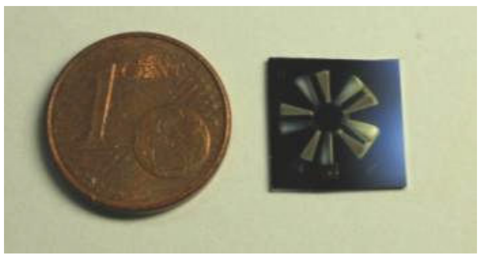
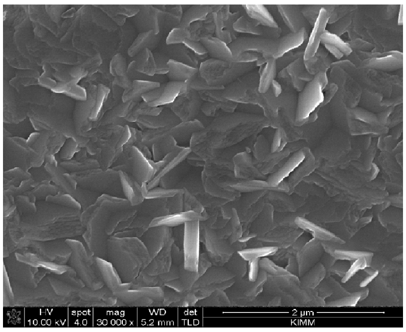


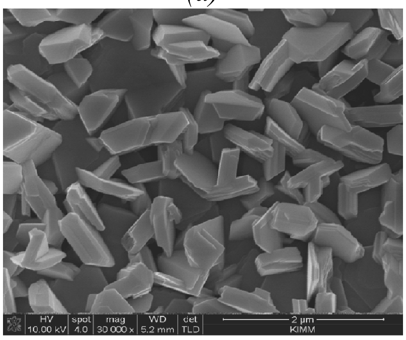
Fig. 5: The fabricated µTEC

TEST & CHARACTERIZATION

Figure 6 shows the surface image of the thermoelectric thin film. P type TE thin film has the larger grain size. The measured thermoelectric properties of the fabricated TE thin film in table 1 show that the thermoelectric films have high quality because of its simple fabrication process in high substrate temperature. Figure 7 shows the experimental set-up of µTEC. It consists of soucemeter (Keithley 2400) for the input current and IR camera system (FLIR Thermovision A40) for the temperature measurement. IR camera system was chosen to measure the temperature of µTEC because the proposed µTEC was so small that the thermocouple cannot be installed easily. Figure 8 shows the temperature distribution of the proposed µTEC. The experiment result in Figure 9 shows the cooling behavior of the proposed TEC with the input current. It shows the temperature difference of 4.7 ℃ between the electrodes at the input current 50 mA. The resistance of the µTEC was 0.648 kΩ.



(a)

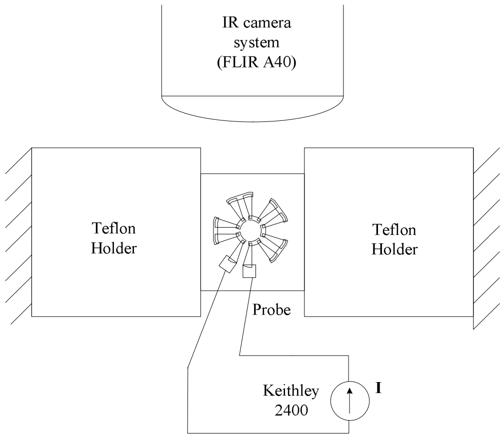


(b)

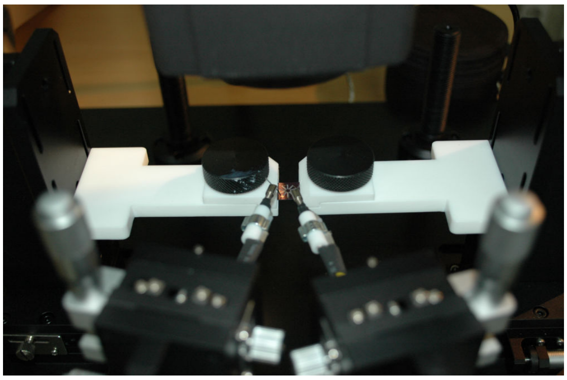
Fig. 6: The surface SEM images of TE thin films: (a) N type (Bi-Te), (b) P type (Bi-Sb-Te).

Table 1: The measured properties of thermoelectric thin films.

	Substrate temp.	n/p ($10^{19}cm^{-3}$)	μ (cm^2/vs)	ρ ($m\Omega cm$)	α ($\mu V/K$)	α^2/ρ ($e^{-5}W/K^2m$)
N type	100℃	-10.6	35	1.74	-140.5	114
P type	100℃	3.24	14.6	13.4	275	56



(a)



(b)

Fig. 7: The experimental set-up: (a) schematic diagram, (b) photograph.

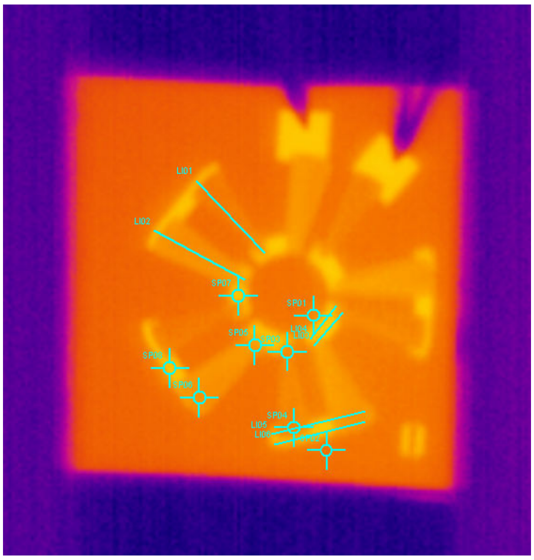


Fig. 8: IR image of the proposed µTEC at the input current 10 mA.

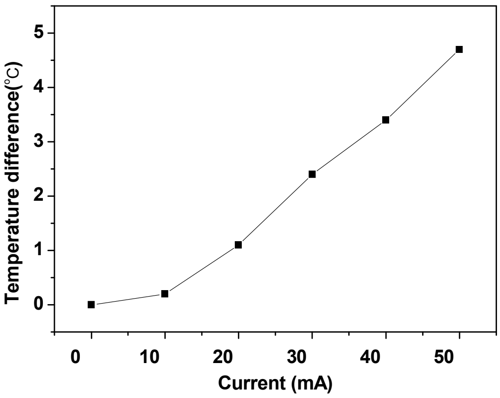


Fig. 9: The temperature difference between point B and point C in Fig. 2.

CONCLUSION

In this paper, the proposed radial type μTEC was fabricated by the stencil lithography with co-sputtering for the active cooling of LED chip. With the stencil lithography, simple fabrication process of the proposed μTEC was realized and thermoelectric material with high quality was deposited. The characterization result of the proposed μTEC acquired by IR camera system shows the feasibility for application in LED cooling.

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