Tunable Metamaterial IR Emitter By Using MEMS Microheater

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***Abstract*—We proposed an effective metamaterial infrared (IR) emitter by using MEMS microheater with different pattern density. A highest heating efficiency of MEMS microheater is under the pattern density of 49%. The metamaterial is composed of π-shape nanostructures on the surface of MEMS microheater to form a metamaterial IR emitter. By changing gap width of π-shape metamaterial, the emissivity of IR emitter is blue shift and enhances its emissivity. The emissivity of metamaterial IR emitter is 0.94 at wavelength of 5 μm. Such design is able to exhibit a narrowband wavelength in IR wavelength range.**

Keywords—MEMS, metamaterial, IR emitter

I. INTRODUCTION

Recently, the infrared (IR) emitters based on the electrical-thermal characteristics of the microheater have been demonstrated. Most of them are utilized the conventional blackbody thermal emission in IR wavelength range. However, the bandwidth of IR emission is broad and limited to the specific wavelength that cannot be used in practical applications. In view of this situation, thermal emission controlled by various types of metamaterial has been proposed and demonstrated to overcome above drawbacks [1]. Furthermore, the efficiency of thermal emission generated from microheater is limited owing to the temperature distribution is not uniform by using traditional meander-type microheater [2].

In the study, we proposed and developed a state-of-the-art pattern of MEMS microheater that can exhibit a higher heating efficiency with a uniform distributed temperature. The pattern of MEMS microheater is a famous space-filling curving in mathematical fractal theory, which covering area contains the entire two-dimensional unit square. Therefore, we compared six designs of MEMS microheater with different pattern density. They are MEMS microheater with pattern density of 16%, 20%, 32%, 38%, 42%, and 49%, respectively. According to these results, the IR metamaterial with π-shape was fabricated on MEMS microheater surface to enhance thermal emission and then realize a high-efficiency IR emitter. Meanwhile, we further discussed the tunability of π-shape metamaterial by changing its gap width. Eventually, the integration of tunable π-shape metamaterial and MEMS microheater will be realized the active tuning IR emitter for widespread applications and other fields.

II. STRUCTURE DESIGN

Fig. 1(a) shows the schematic drawing of proposed metamaterial IR emitter. The device is composed of MEMS microheater covered with a SiO_2 layer on Si substrate and an IR metamaterial atop. The material of MEMS microheater and metamaterial is gold (Au) with the same 200 nm in thickness. The emission area of device is 500×500 μm^2. On the top of IR emitter, periodic metamaterials with a thickness of 200 nm are patterned on SiO_2 surface. It is composed of three rectangular bars to form π-shape metamaterial as is shown in Fig. 1(b). The relative geometrical dimensions of π-shape metamaterial are also indicated as in Fig. 1(b).

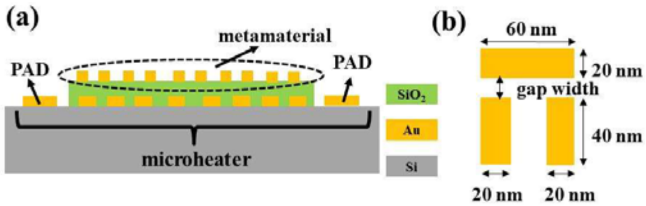

Fig. 1. (a) Schematic drawing of proposed metamaterial IR emitter. (b) Geometrical dimensions of π-shape metamaterial unit cell.

III. RESULTS AND DISCUSSIONS

To make MEMS microheater with optimal electrical-thermal efficiency, we designed and compared MEMS microheaters with six effective pattern densities (D_{eff}, the ratio of effective heating material to the whole area of microheater). The D_{eff} values are 6%, 20%, 32%, 38%, 42%, and 49%, respectively. Fig. 2 shows the experimental results of MEMS microheaters under different driving voltage. The inserted images are top view of optical microscopies for six microheaters designs. It is clear to be observed the higher D_{eff} has high-efficiency to realize the uniform distribution of temperature. The electrical-thermal efficiency increases with D_{eff}. The heating temperature can reach 300 °C, which is approximately 580 K in Kelvin scale at the driving voltage of 35 V under the condition of D_{eff} = 49%. It exhibits a higher efficiency than traditional work [2]. According to the equation of blackbody emission expressed by

$$\rho_\lambda d\lambda = \frac{8\pi hc}{\lambda^5}\frac{1}{\exp(hc/\lambda kT)-1}d\lambda \quad (1)$$

where ρ_λ, λ, h, c, k, and T are emission per unit volume, wavelength of emission, Plank constant, velocity of light in vacuum, Boltzmann constant, and temperature, respectively.

The calculation results of blackbody emission are shown in Fig. 3. The maximum emission is 580 K at wavelength of 5 μm, which is identical to the heating temperature of our proposed MEMS microheater with effective pattern density of 49%. As the above experimental results, we further utilized π-shape metamaterial to enhance the IR emission generated by MEMS microheater to overcome the broad spectral bandwidth of blackbody emission. Fig. 4(a) exhibits the transmission spectra of π-shape metamaterial by changing the gap width as indicated in Fig. 1(b). The electromagnetic responses are blue shift from 6.8 μm to 4.3 μm by changing gap width of π-shape metamaterial from 0 nm to 25 nm. Meanwhile, transmission intensity of π-shape metamaterial is gradually increasing to reach 1 by increasing the gap width, while the spectral bandwidth becomes broad. The relationship of gap width of π-shape metamaterial to transmission intensity is shown in Fig. 4(b). It is a trade-off to have a high transmission intensity and narrow spectral bandwidth. In Fig. 4(a), it is clear to be observed that the transmission intensity is at wavelength of 5 μm under the condition of gap width of 10 nm. The emissivity and bandwidth of device with π-shape metamaterial and MEMS microheater are 0.94 and 1 μm as shown in Fig. 5. The bandwidth is enhanced 5.6-fold compared to that of blackbody emission at 580 K as shown in Fig. 3. The corresponding electric (E) and magnetic (H) field distributions are shown in the inserted images of Fig. 5. Therefore, the use of π-shape metamaterial with gap width of 10 nm on MEMS microheater surface isolated with a SiO_2 layer can successfully realize tunable IR emission at wavelength of 5 μm with a narrow bandwidth.

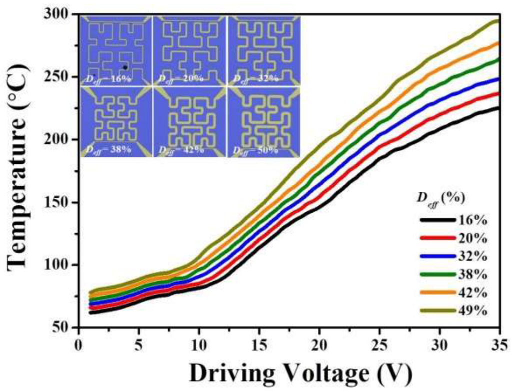

Fig. 2. The temperature as a function of driving voltage for six MEMS microheater designs with different pattern density.

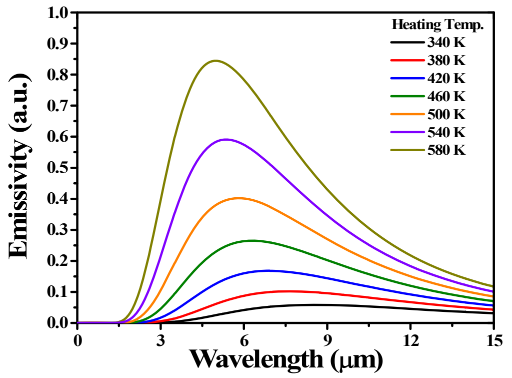

Fig. 3. The blackbody emissivity as a function of different heating temperature.

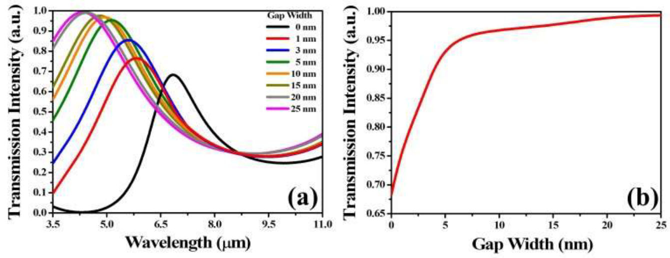

Fig. 4. (a) The transmission spectra of π-shape metamaterial with different gap width. (b) The transmission intensity as a function of gap width.

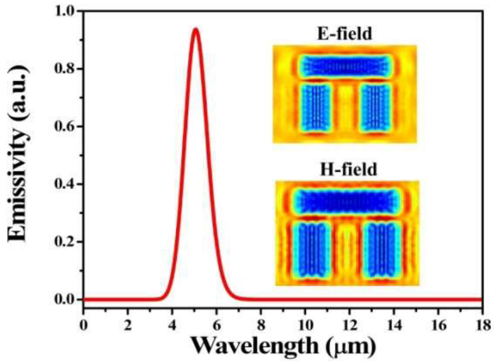

Fig. 5. Emissivity of π-shape metamaterial with a heating temperature of 580 K. The inserted images are E- and H-field distributions at gap width of 10 nm.

IV. Conclusion

In conclusion, an on-chip tunable metamaterial IR emitter is presented. This tunable IR emitter is composed of novel MEMS microheater and π-shape metamaterial. We proposed six designs of MEMS microheater and compared their electrical-thermal efficiency . The experimental results indicate that the heating performance can reach 300 °C at the driving voltage of 35 V under the condition of D_{eff} = 49%. By using the π-shape metamaterial with a gap width of 10 nm, the IR emission could be narrowed and generated an IR emission at wavelength of 5 μm. Such results pave a way for the use of metamaterial in IR emitter application and further to be used in widespread sensors applications, such as gas sensors, chemical sensors, biosensors, and so on.

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References

[1] H. T. Miyazaki, T. Kasaya, H. Oosato,Y. Sugimoto, B. Choi, M. Iwanaga, and K. Sakoda, “Ultraviolet-nanoimprinted packaged metasurface thermal emitters for infrared CO_2 sensing”, *Sci. Technol. Adv. Mater.*, vol. 16. pp. 1-5, 2015.

[2] L. L. R. Rao, M. K. Singha, K. M. Subramaniam, N. Jampana, and S. Asokan, “Molybdenum Microheaters for MEMS-Based Gas Sensor Applications: Fabrication, Electro-Thermo-Mechanical and Response Characterization”, *IEEE Sens. J.*, vol. 17. pp. 22-29, 2017.