2019 International Conference on Optical MEMS and Nanophotonics
July 28 - August 1, 2019 / KAIST, Daejeon, Korea

Fano-resonance of reshaping infrared cross-shape metamaterial (CSM)

Jitong Zhong, Ruijia Xu, Dongyuan Yao, Ji Luo, Yangbin Yu, Zefeng Xu, and Yu-Sheng Lin*
State Key Laboratory of Optoelectronic Materials and Technologies,
School of Electronics and Information Technology, Sun Yat-Sen University,
Guangzhou 510275, China
linyoush@mail.sysu.edu.cn

***Abstract*-An infrared (IR) cross-shape metamaterial (CSM) is presented. The configuration is composed of double Au layers with cross-shape nanostructures. The aspect ratio and length ratio of CSM are compared and discussed to investigate the Fano-resonance within CSM nanostructures. The electromagnetic responses exhibit large tuning range, tunable broad and narrow bandwidths characteristics. By tailoring the aspect ratio of CSM, the resonance could be modified with bidirectional tuning in a range of 650 nm. While the change of length ratio of CSM, there are narrowband resonances around 4.6 μm and broadband resonances in the range of 5.0 to 6.5 μm. These characteristics of CSM with different aspect ratio and length ratio could be potentially used in IR narrowband and broadband filter. To further increase the flexibility of CSM, we propose a tunable CSM using MEMS-based electrothermal actuation mechanism to perform actively tunable narrowband and broadband filter. This study provides a unique approach to realize an IR filter with high-flexibility.**

Keywords—metamaterials, multi-functionalities, IR filter

I. Introduction

Metamaterials are artificial materials that make human capable to control the electromagnetic wave by properly tailoring. They are widely reported and demonstrated in many fields, such as cloaking devices, high-sensitive sensors, perfect absorbers, security screening, medical imaging, and non-destructive testing [1-3]. Metamaterial filter is one of the most important opto-electronic devices due to a wide variety of potential applications in color filters, light emitters and imaging devices, etc [1].

In this study, we propose a cross-shape metamaterial (CSM) in infrared (IR) wavelength range. CSM is composed of double tailored Au layers on Si substrate. The top metal layer is a free-standing structure, which exhibits high flexibility by modifying geometrical dimensions of top metamaterial. By changing geometrical configurations of metamaterials, CSM shows different electromagnetic characteristic and flexible tunability. The corresponding Fano-resonances within CSM nanostructures are investigated to figure out the suitable design in different optical application.

II. Materials and Methods

Fig. 1 shows the schematic drawing of proposed CSM. It is composed of double tailored Au layers with a gap between them. The geometrical parameters are metallic lengths along x-axis and y-axis, which are denoted as L_1 and L_2, respectively. The metallic width (W) of CSM is varied simultaneously when discussed the electromagnetic characteristics in this study. The metallic thicknesses of two Au layers are kept as constant as 200 nm. The gap is also kept as constant as 100 nm. Herein, the reconfiguration of CSM is proposed to compared and discussed different aspect ratio (t = W/L), length ratio (r = L_1/L_2), and rotation angle of top metamaterial layer.

III. Results and Discussions

The transmission and reflection spectra of CSM with different t (W/L) value in IR wavelength range under the condition of $L_1 = L_2 = 2000$ nm are shown in Fig. 2(a) and Fig. 2(b), respectively. When t = 200 nm / 2000 nm = 0.1, the resonances of transmission and reflection spectra are at 5.55 μm. By increasing t value from 0.1 to 1.0 (from 200 nm / 2000 nm to 2000 nm / 2000 nm), the resonances are blue-shift 400 nm first from t = 0.1 to t = 0.5 (from 200 nm / 2000 nm to 1000 nm / 2000 nm), and then red-shift 650 nm from t = 0.5 to t = 1.0 (from 1000 nm / 2000 nm to 2000 nm / 2000 nm). These results clearly show that CSM exhibits a bidirectional characteristic by changing t value under the condition of $L_1 = L_2 = 2000$ nm. The transmission spectra of CSM with different r (L_1/L_2) value under the conditions of W = 200 nm, 400 nm, 800 nm and 1200 nm by keeping the $L_1 = L_2 = 2000$ nm are shown in Fig. 3. In Fig. 3(a), the resonant peak is blue-shift 50 nm from wavelength of 4.70 μm (r = 0.1) to 4.65 μm (r = 1.0) and the resonant dip is blue-shift 70 nm from wavelength of 5.62 μm (r = 0.1) to 5.55 μm (r = 1.0). By increasing the metallic width to 400 nm (W = 400 nm), the resonant peak is blue-shift 100 nm from wavelength of 4.66 μm (r = 0.2) to 4.56 μm (r = 1.0) and the resonant dip is blue-shift 140 nm from wavelength of 5.52 μm (r = 0.2) to 5.38 μm (r = 1.0) as shown in Fig. 3(b). When W = 800 nm, the first resonance is red-shift 330 nm from wavelength of 4.82 μm (r = 0.4) to 5.15 μm (r = 1.0) and the second resonance is red-shift 340 nm from wavelength of 6.08 μm (r = 0.4) to 5.38 μm (r = 0.6) as shown in Fig. 3(c). In the case of W = 1200, the full width at half maximum (FWHM) of resonance can be tuned from 180 nm to 500 nm by changing r = 0.6 to r = 1.0 as shown in Fig. 3(d).

To further investigate the tunability of CSM device, it is designed to rotate an angle between double tailored Au layers by using MEMS electrothermal actuator. Here, we choose the condition of W = 800 nm as an example as shown in Fig. 4. Fig. 4(a) shows the schematic drawing of proposed MEMS-based CSM. The resonances of transmission and reflection spectra of MEMS-based with different rotation angle are shown in Fig. 4(b) and Fig. 4(c), respectively. By changing the rotation angle from 0° to 45°, the resonance of transmission spectra can be tuned the FWHM of device, i.e. spectrum bandwidth from 300 nm to 1200 nm as shown in Fig. 4(b), while the narrowband resonance of reflection spectra is blue-shift 200 nm from 4.37 μm to 4.17 μm as shown in Fig. 4(c). It is clearly observed the proposed MEMS-based CSM device exhibits the tunable abilities of broad and narrow bandwidth for transmission and reflection spectra, respectively. Such tuning approach provides a suitable design for tunable IR filter application with high-flexibility.

978-1-7281-4503-7/19/$31.00 ©2019 IEEE

IV. Conclusion

In conclusion, a reshaping CSM is presented, which is composed of double Au metamaterial layers. By tailoring the geometrical dimensions of CSM, the corresponding electromagnetic behavior exhibits large tuning range of resonance, tunable bandwidth, and tunable narrowband resonance characteristics. The variation of t value shows the resonance could be modified with red-shift 400 nm and blue-shift 650 nm to form the bidirectional tuning. While the variation of r value shows the transmission bandwidths could be modified to be narrow around 4.6 µm and broad in the range of 5.0 to 6.5 µm. These characterizations of CSM with different t and r values could be potentially used in high-efficiency IR narrowband and broadband filter. Furthermore, we propose an active tuning mechanism using MEMS electrothermal actuator to increase the flexibility of CSM. This approach exhibits CSM could be tuned the bandwidth by rotating the top cross-shape metamaterial. By rotating an angle from 0º to 45º, the electromagnetic bandwidth is tuned from 300 nm to 1200 nm. It is enhanced 4-fold. These results open an avenue for filter, absorber, detector, sensor, and switch applications with high-flexibility in IR wavelength range.

Acknowledgment

The authors acknowledge the financial support from research grants of 100 Talents Program of Sun Yat-Sen University (grant number 76120-18841202) and the State Key Laboratory of Optoelectronic Materials and Technologies of Sun Yat-Sen University for the use of experimental equipment.

References

[1] A. Lochbaum, Y. Fedoryshyn, A. Dorodnyy, U. Koch, C. Hafner, and J. Leuthold, "On-Chip Narrowband Thermal Emitter for Mid-IR Optical Gas Sensing," *ACS Photonics*, vol. 4, pp. 1371-1380, 2017.

[2] Hwang. I, Yu. J, Lee. J, Choi. JH, Choi. DG, Jeon. S, Lee. J, Jung. JY, "Plasmon-Enhanced Infrared Spectroscopy Based on Metamaterial Absorbers with Dielectric Nanopedestals," *ACS Photonics*, vol. 5, pp. 3492-3498, 2018.

[3] M. Bağmancı, M. Karaaslan, E. Ünal, O. Akgol, F. Karadağ, and C. Sabah, "Broad-band polarization-independent metamaterial absorber for solar energy harvesting applications," *Physica E*, vol. 90, pp. 1-6, 2017.

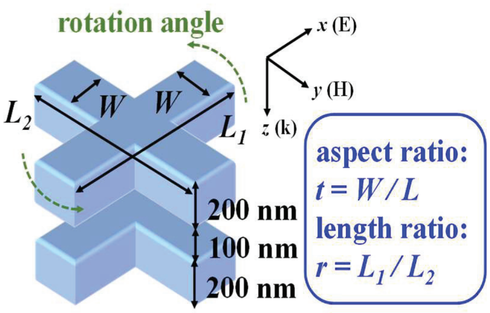

Fig. 1. Schematics drawing of proposed CSM and corresponding denotaions of geomertical dimensions.

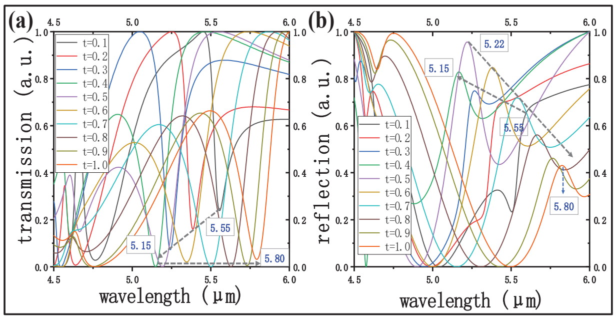

Fig. 2. (a) Transmission and (b) reflection spectra of CSM with different t value under the condition of $L_1 = L_2$.

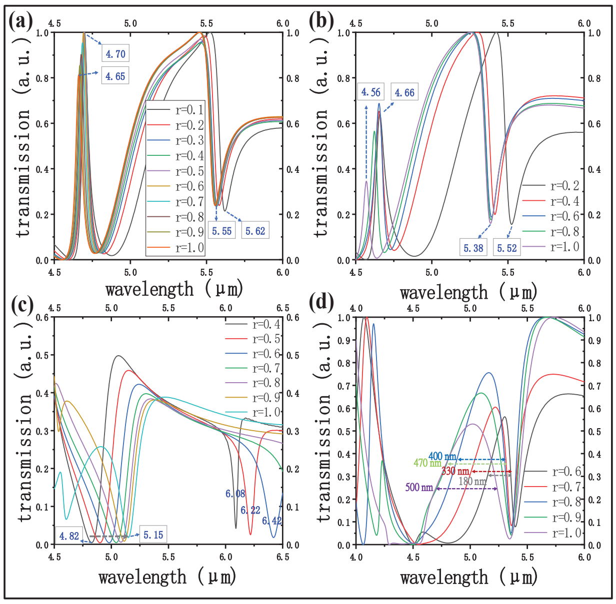

Fig. 3. Transmission spectra of CSM with different r value under the conditions of (a) $W = 200$ nm, (b) $W = 400$ nm, (c) $W = 800$ nm, and (d) $W = 1200$ nm, respectively.

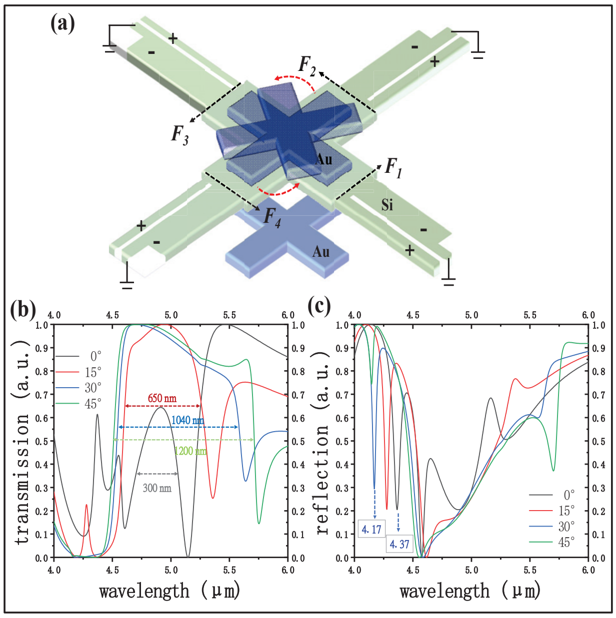

Fig. 4. (a) Schematic drawing of CSM integrated with MEMS electrothermal actuator to perform rotary displacement. (b) Transmission and (c) reflection spectra of MEMS-based CSM with different rotation angle under the conditions of $W = 800$ nm.