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Chalcogenide Glass for Infrared Meta-Absorber

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***Abstract*—We propose a novel infrared (IR) meta-absorber by using chalcogenide glass (ChG) material. The merits of ChG are zero extinction coefficient, excellent IR transparency, high third-order nonlinearity, adjustable refraction index, dispersion, and energy bandgap in IR wavelength range. Therefore, it is very suitable for the meta-absorber design. This ChG-based meta-absorber is composed of ring-disk nanostructures. The resonant wavelength and intensity of reflection spectra could be tuned by changing the outer ring of ring-disk nanostructures in horizontal and vertical displacements. The maximum quality factor (Q-factor) is 625. These unique characteristics of IR meta-absorber with ring-disk nanostructures can be used as a tunable IR filter and multi-resonance switch. Furthermore, the proposed device exhibits superior electromagnetic behaviors to be used as a high-efficiency environmental sensor.**

Keywords—metamaterial, infrared, switch, absorber

I. Introduction

Metasurface is artificially planar metamaterial configured with periodic or aperiodic structures, which shows extraordinary electromagnetic characterizations. The development of metasurface can greatly reduce the volume and weight of conventional optical devices, such as optical filter, switch, nanophotonic, waveguide, sensor, high-resolution imaging, and so on [1]. Recently, there have been reported many literatures for metasurface-based optoelectronic devices. Although there are extensive efforts in passive and active devices for potential applications [2-4], their optical performances are not perfect for widespread applications in considerations of high portability, applicability, and cost-effectiveness characterizations. Such characteristics of active metasurface-based devices might minimize limitations of time and space in the uses of energy harvesting, emitter, detector, photovoltaic cell, spectroscopy, sensor and other fields.

Herein, we propose an effective design to demonstrate a high-efficiency meta-absorber using novel material of chalcogenide glass (ChG). This ChG-based meta-absorber is composed of ring-disk nanostructures on Si substrate coated an Au mirror layer atop. By tailoring the space distributions, i.e. horizontal displacement of outer ring and gap between inner disk and outer ring, the resonant frequency and intensity of ChG-based meta-absorber could be modified to perform a multi-resonance switch with ultra-high Q-factor. To further investigate the proposed device can be used in practical applications, ChG-based meta-absorber is surrounded with different environmental media. The results show the design is a high-precision refraction index sensor.

II. Materials and Methods

Fig. 1(a) shows the schematic of proposed ChG-based meta-absorber with ring-disk nanostructures on Si substrate coated with an Au mirror layer atop. The thickness of Au mirror layer is 400 nm. The geometrical parameters as kept as constant. They are diameter of outer ring (R = 1.2 μm), diameter of inner disk (r = 0.8 μm), and refraction index of ChG (n_m = 2.4, Ge: 11.5%, As: 24%, Se: 64.5%), respectively. The line width of ring and period are also kept as constant as 300 nm and 3 μm, respectively. The variations of gap between inner disk and outer ring (g), horizontal displacement of outer ring (d), and refraction index of surrounding environment (n_0) will be compared and discussed in this study. The inner disk is fixed on Au/Si substrate and the outer ring is designed to be suspended and adjustable. The gap between inner disk and outer ring and horizontal displacement of outer ring can be modified by using electrostatic or electrothermal actuation mechanism to realize tunable ChG-based meta-absorber as the SEM images shown in Fig. 1(b). According to the propagation and attenuation of surface plasmon polaritons (SPPs) on meta-absorber [5], it can generate the collective oscillation of free electrons within meta-absorber when the wave vector of SPPs is equal to that of incident electromagnetic wave. That will result in the resonance or absorbance at certain wavelength.

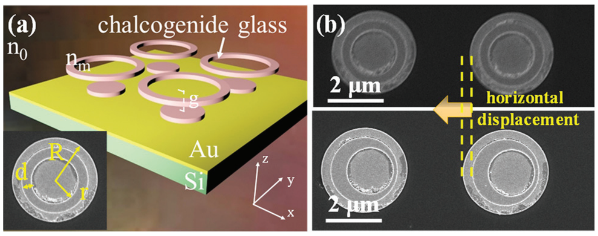

Fig. 1. (a) Schematic of tunable IR meta-absorber with multi-resonances switch. The denotations are diameter of outer ring (R = 1.2 μm), diameter of inner disk (r = 800 nm), gap between inner disk and outer ring (g), horizontal displacement of outer ring (d), refraction index of air (n_0), and refraction index of ChG (n_m = 2.4), respectively. (b) SEM images of ChG-based meta-absorber with a horizontal displacement of outer ring.

III. Results and Discussions

Fig. 2 shows the reflection spectra of ChG-based meta-absorber with ring-disk nanostructures by changing d from 0.4 μm to 0 μm. The g value is 0 μm. There are three resonances at 3.075 μm, 3.125 μm, and 3.175 μm wavelengths. At d = 0.4 μm, there is a resonance at 3.125 μm wavelength caused from ring-disk nanostructures is asymmetrical structure, whose corresponding Q-factor is 479. By shrinking d, the resonance of 3.125 μm wavelength will be vanished gradually, while the adjacent both resonances (at 3.075 μm and 3.175 μm wavelengths) will be generated gradually. There is almost only one resonance at 3.125 μm wavelength that resonance intensity is decreased gradually. At this attenuation situation, the maximum Q-factor is 567. When the outer ring of ring-disk nanostructures is continuously close to central disk with d = 0.25 μm, d = 0.20 μm, and d = 0.15 μm as shown in Fig. 2, there has three resonances at 3.075 μm, 3.125 μm, and 3.175 μm wavelengths. The outer ring of ring-disk

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nanostructures is close to central disk with d = 0.10 μm, d = 0.05 μm, and then touches each other (d = 0 μm). The central resonance (3.125 μm wavelength) is gradually vanished and the both resonances become stronger. The maximum Q-factors are 439 and 489 for resonances at 3.075 μm and 3.175 μm wavelengths, respectively. These resonances exhibit high-performance attenuation and switch in resonance intensity that can be used for multi-resonance switch application. Therefore, the proposed ChG-based meta-absorber with ring-disk nanostructures possesses multi-resonance switch function.

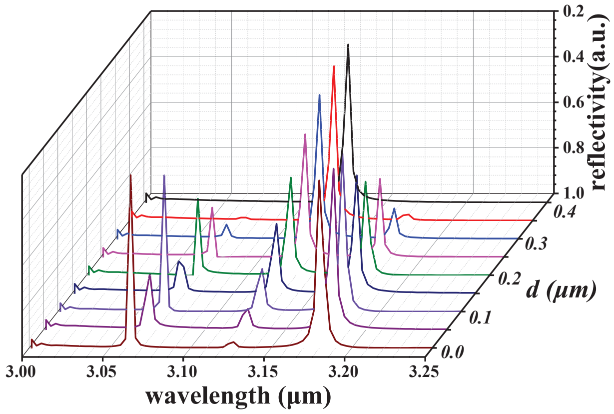

Fig. 2. Reflection spectra of ChG-based meta-absorber with ring-disk nanostructures by changing horizontal displacement of outer ring (d).

Fig. 3(a) shows the reflection spectra of ChG-based meta-absorber with ring-disk nanostructures with different g from 0 μm to 3 μm. The other geometrical parameters are kept at d = 0.4 μm, respectively. The resonance is blue-shift by increasing g. The effective tuning range of resonance is between g = 0 μm to 1.5 μm and has not evident resonance at g = 3 μm. According to guide-mode theory, the Q-factor of device can be enhanced by changing g. The maximum Q-factor is at the condition of g = 1 μm, which is 625. The corresponding E and H-fields distributions are shown in inserted images of Fig. 3(a). The electromagnetic energy is focused on the gap of inner disk and outer ring of ring-disk nanostructures. The optimized geometrical parameters to earn ultra-high Q-factor are d = 0.4 μm, and g = 1 μm.

In order to prove the applicability of proposed ChG-based meta-absorber with ring-disk nanostructures, the device is immersed into surrounding environment with different ambient refraction index to demonstrate high-efficiency environmental sensor application. Fig. 3(b) shows the reflection spectra of ChG-based meta-absorber with ring-disk nanostructures by changing ambient reflection index (n_0) from 1.0 to 1.9. The geometrical parameters are kept at g = 0 μm and d = 0.4 μm. The resonance intensity is decreased gradually by increasing n_0. The Q-factors are in the range of 265-370. The corresponding relationship of resonance and n_0 is summarized in the inserted image. The trend is linear, whose correlation coefficient is 0.99999. Such design can be used as a high-efficiency environmental sensor.

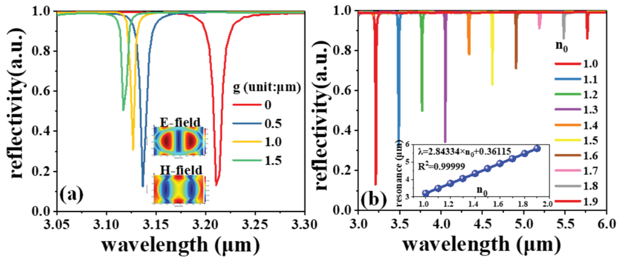

Fig. 3. Reflection spectra of tunable IR meta-absorber with (a) different gap between inner disk and outer ring (g) and (b) with different ambient reflection index (n_0).

IV. Conclusion

In conclusion, we present a novel IR meta-absorber composed of ChG in the configuration of ring-disk nanostructures. The device possesses tunabilities of resonance and reflection intensity. By tailoring the geometrical dimensions, the reflection spectra of ChG-based meta-absorber with ring-disk nanostructures can be attenuated and modified for tunable filter and multi-resonance switch applications. The reflection spectra can be tuned and switched by changing the distance of outer ring and inner disk of ring-disk nanostructures. The maximum Q-factor is 625 for IR filter and 567 for multi-resonance switch. To further demonstrate the proposed device can be used as high-efficiency environmental sensor, device is immersed into surrounding environment with different ambient refraction index from 1.0 to 1.9. The Q-factors are in the range of 265-370 with a linear relationship, whose corresponding correlation coefficient is 0.99999. Such proposed ChG-based meta-absorber with ring-disk nanostructures exhibits unique characteristics for high-performance optoelectronic devices, which will open an avenue to widespread applications, such as filter, multi-resonance switch, thermal emitter, photodetector, environmental sensor and so on.

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References

[1] C. M. Soukoulis and M. Wegener, "Past achievements and future challenges in the development of three-dimensional photonic metamaterials," *Nat. Photonics*, vol. 5, pp. 523–530, 2011.

[2] K. Chen, R. Adato, and H. Altug, "Dual-band perfect absorber for multispectral plasmon-enhanced infrared spectroscopy," *ACS Nano*, vol. 6, pp. 7998–8006, 2012.

[3] J. J. Talghader, A. S. Gawarikar, and R. P. Shea, "Spectral selectivity in infrared thermal detection," *Light-Sci. Appl.*, vol. 1, p. 24, 2012.

[4] F. Guo, T. Sun, F. Cao, Q. Liu, and Z. Ren, "Metallic nanostructures for light trapping in energy-harvesting devices," *Light-Sci. Appl.*, vol. 3, p. 161, 2014.

[5] Y. S. Lin and W. Chen, "A Large-Area, Wide-Incident-Angle, and Polarization-Independent Plasmonic Color Filter for Glucose Sensing," *Opt. Mater.*, vol. 75, pp. 739-743, 2018.