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Tunable broadband near-infrared absorber based on ultrathin phase-change material

Er-Tao Hu [a,1], Tong Gu [a,1], Shuai Guo [a], Kai-Yan Zang [b], Hua-Tian Tu [b], Ke-Han Yu [a], Wei Wei [a,*], Yu-Xiang Zheng [b], Song-You Wang [b], Rong-Jun Zhang [b], Young-Pak Lee [c], Liang-Yao Chen [b,*]

[a] School of Optoelectronic Engineering, Nanjing University of Posts and Telecommunications, Nanjing, 210023, China
[b] Department of Optical Science and Engineering, Fudan University, Shanghai, 200433, China
[c] Department of Physics, Hanyang University, Seoul, 04763, Republic of Korea

A R T I C L E I N F O

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A B S T R A C T

In this work, a tunable broadband near-infrared light absorber was designed and fabricated with a simple and lithography free approach by introducing an ultrathin phase-change material $Ge_2Sb_2Te_5$ (GST) layer into the metal–dielectric multilayered film structure with the structure parameters as that: SiO_2 (72.7 nm)/$Ge_2Sb_2Te_5$ (6.0 nm)/SiO_2 (70.2 nm)/Cu (>100.0 nm). The film structure exhibits a modulation depth of ~72.6% and an extinction ratio of ~8.8 dB at the wavelength of 1410 nm. The high light absorption (95%) of the proposed film structure at the wavelength of 450 nm in both of the amorphous and crystalline phase of GST, indicates that the intensity of the reflectance in the infrared region can be rapidly tuned by the blue laser pulses. The proposed planar layered film structure with layer thickness as the only controllable parameter and large reflectivity tuning range shows the potential for practical applications in near-infrared light modulation and absorption.

Nano/micro-structured plasmonic and metamaterial absorbers have received tremendous attention in past few years due to the important applications in the infrared and visible regions of the spectrum including infrared detection [1], solar energy harvesting [2,3], spatial light modulation [4,5] and refractive index sensing [6]. To control and manipulate the absorption intensity and resonant bandwidth for specific applications, the size and geometry of the nanostructure must be engineered [2]. Nevertheless, nanostructured devices with dynamically tunable or actively switchable properties have very attractive features for many practical applications [7]. It can be realized by employing certain tunable materials in the design in terms of the optical properties of the material which can be effectively tuned by electrical, optical and thermal stimulus [7,8].

For phase-change materials (PCM) such as VO_2 and $Ge_2Sb_2Te_5$ (GST), their optical properties can be optically or electrically switched because their dielectric properties undergo a substantial change during the amorphous-to-crystalline phase transition [2,6]. By including the PCM into the metamaterial structure, many different devices have been proposed such as the light modulator [1,9], tunable light absorbers [4,6], and nanoantennas [10]. However, the phase-transition in VO_2 is volatile with its phase only being stable within certain temperature range, implying inefficiency in energy transfer and impractical implement in electrically controlled circuits at the nanoscale [1,11]. In contrast, GST is non-volatile with the particular phase state to be maintained without requirement of additional power input. Thus, once the phase state is switched, the optical properties of the state will be kept until the phase is switched again. This type of feature is unique to make the GST-based devices quite attractive for a green technology perspective [6].

The GST-based metamaterial absorbers, which are typically consisting of two Au layers separated by a GST layer with the top Au layer patterned into square [6,12,13], disk [4], strip [1], have been proposed. Broadband tunable absorption properties were realized through changing the phase state of GST. In the work done by Chen et al. [4], the plasmonic resonance peak shifts significantly by a range of about 650 nm with the absorption maintained at the value above 0.96 as the crystallization level of GST is changed from the amorphous to the crystalline phase state. However, the fabrication processes are often complex, time-consuming and expensive, to mean less suitable for mass production of the devices in cost-effective applications. In contrast, lithography-free planar multilayered film structures have the advantage of requiring minimal fabrication steps [2,5] to benefit for large scale

* Corresponding authors.
E-mail addresses: iamww@fudan.edu.cn (W. Wei), lychen@fudan.ac.cn (L.-Y. Chen).
[1] The first two authors contributed equally to this work.

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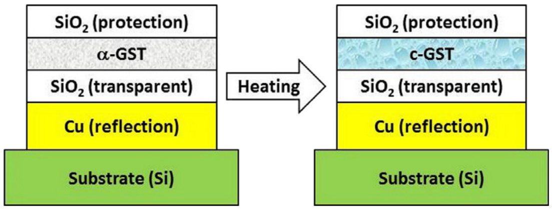

Fig. 1. Schematic diagram of the 4-layered film structure.

production. By replacing the dielectric layer with indium tin oxide (ITO), the planar 4-layered film structure of ITO/GST/ITO/Pt shows the potential for applications in ultrafast solid-state nano-displays [11,14].

In this work, 4-layered SiO_2/GST/SiO_2/Cu film structures were designed and deposited by magnetron sputtering at room temperature. Then the sample was annealed at 200 °C for 1 h under the vacuum of $4{\times}10^{-6}$ Torr to crystallize the sample. Afterwards, the reflectance spectra of the sample before and after annealing process in the wavelength range of 200–3000 nm were measured and compared with the simulated results.

The transfer matrix method (TMM) was used to simulate the reflectance (R), absorptance (A) and transmittance (T) spectra of the proposed SiO_2/GST/SiO_2/Cu film structure with the schematic diagram showing in Fig. 1. The optical constants for Cu and SiO_2 were obtained from the database of Palik [15], while the optical constants of GST in the amorphous and crystalline state were obtained from the reference [16]. The thickness of Cu layer was set to be greater than 100 nm for assuring the transmittance through the 4-layered film structure to be very low. Then, based on the energy conservation law, the absorptance spectra can be readily reduced from $A = 1 - R$, due to $T = 0$. The thickness for the SiO_2 and GST layers in simulation was obtained by fitting the target of $A = 1$ in the wavelength region of 300–1600 nm when GST is in its crystalline state with the specific parameters as that: SiO_2 (72.7 nm)/$Ge_2Sb_2Te_5$ (6.0 nm)/SiO_2 (70.2 nm)/Cu (>100.0 nm).

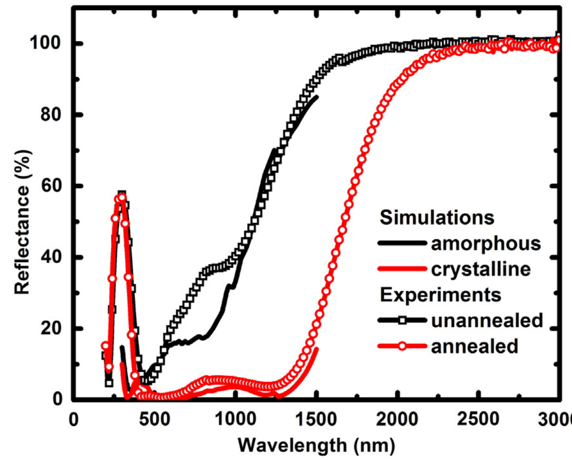

Fig. 3. Measured and simulated reflectance spectra of the 4-layered film structures.

The GST, Cu and SiO_2 layers were deposited on the optically polished Si substrate by direct current (DC) and radio frequency (RF) sputtering methods (Infovion EBAS sputtering system, Seoul, Korea) at room temperature with a background pressure of 4.5×10^{-6} Torr. The growth pressure was fixed at 1 mTorr by a throttle valve with the argon (Ar) gas flow rate of 10 sccm (standard cubic centimeter per minute). The growth power for GST, Cu and SiO_2 was fixed at 20 W, 100 W and 150 W, respectively. The growth rate for the GST and Cu layers was calibrated by using a step profiler, while the growth rate of the SiO_2 layer was determined by a spectroscopic ellipsometer.

GST changes its phase state from the amorphous to the face-centered-cubic (fcc) state at about 150 °C [17,18]. In order to crystallize the GST-based 4-layered film structure, the fabricated sample was annealed at 200 °C for 1 h at the vacuum of 4.5×10^{-6} Torr in the Infovion chamber. Then the structure and phase of the unannealed and annealed sample

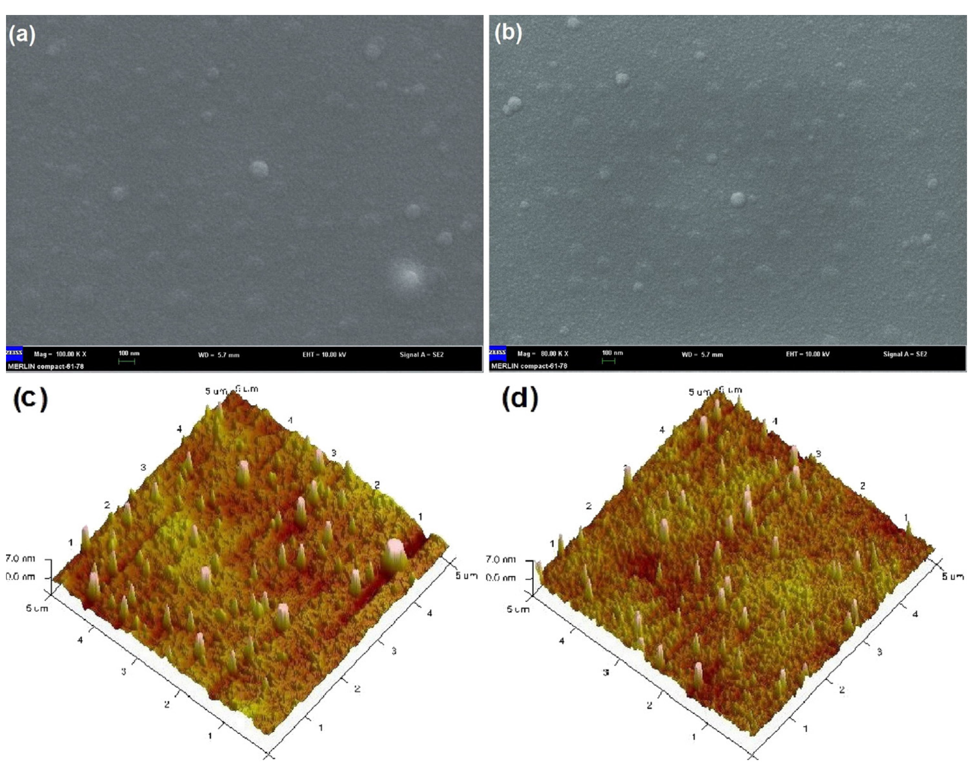

Fig. 2. SEM and AFM images for the unannealed sample (a and c) and annealed sample (b and d).