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Tunable Electromagnetically Induced Transparency in Ge₂Sb₂Te₅-Based Infrared Metasurfaces

Riad Yahiaoui¹, Sirak M. Mekonen¹, Joshua A. Burrow², Jay Matthews³, Imad Agha^{2,3}, Andrew Sarangan² and Thomas Searles¹

¹Dept. of Physics & Astronomy, Howard University, Washington, DC USA

²Electro-Optics Department, University of Dayton, Dayton, OH USA

³Department of Physics, University of Dayton, Dayton, OH USA

Authors e-mail addresses: (riad.yahiaoui@howard.edu, thomas.searles@howard.edu)

Abstract: We report the investigation of an all-dielectric metasurface (ADM) based on an array of Ge₂Sb₂Te₅ (GST) meta-molecules exhibiting a tunable electromagnetically induced transparency (EIT) effect in the infrared frequency regime.

OCIS codes: (000.0000) General; (000.0000) General [8-pt. type] For codes, see <http://www.osapublishing.org/submit/ocis/>

1. Introduction

Electromagnetically induced transparency (EIT) effect is initially observed in atomic systems and arises due to quantum interference, resulting in a narrowband transparency window for light propagating through an originally opaque medium [1]. This concept was later extended to classical optical systems such as plasmonic structures and metamaterials (MMs) [2,3].

Most terahertz (THz) and optical MMs reported so far were based on miniaturizing the concept of structured composites with patterned metallic subwavelength inclusions [4,5], first introduced at microwave frequencies [6]. The properties of MMs rely on strong electromagnetic resonances and consequently, their effective electromagnetic behavior and the aimed applications are restricted to narrow spectral intervals. Active spectral tuning of the MM resonance then appears as highly desirable for broadband applications. Several techniques of tunability have been explored and demonstrated in literature such as integrating graphene and transition metal dichalcogenides (TMDCs) [7,8], localized active components [9], electrically [10], optically [11] and thermally-driven materials [12,13].

In this paper, we report on a demonstration of a tunable MM exhibiting an analogue of electromagnetically induced transparency in the infrared spectral range. The tunability property of the proposed metamaterial is achieved by using the phase-change material (PCM) Ge₂Sb₂Te₅ (GST) alloy. GST is known to exhibit a high dielectric tunability in the infrared range while its dielectric losses remain at an acceptable level [14].

2. Design, results and discussions

The unit cell of the investigated metadvice is schematically shown in Fig. 1(a). It is composed of a disk resonator (DR) and a pair of cut wire resonators (CWRs) deposited on the top side of a silicon (Si) substrate. The nanoresonators are made of 50-nm-thick GST and the relevant geometrical dimensions are: $p_x = p_y = 1 \mu\text{m}$, $l_1 = 4.1 \mu\text{m}$, $l_2 = 3.2 \mu\text{m}$, $l_3 = 2.3 \mu\text{m}$ and $w = 0.75 \mu\text{m}$. Such periodic structure does not diffract normally incident electromagnetic radiation for frequencies less than 300 THz.

Numerical calculations were carried out using the finite difference time domain (FDTD) technique. In these calculations, the elementary cell of the designed metasurface was irradiated at normal incidence, under TE-polarization ($E \parallel y$ -axis), as indicated in Fig. 1(a). Periodic boundary conditions were applied in the numerical model in order to mimic the functioning of a 2D infinite structure. In simulations, the silicon substrate was treated as a lossless dielectric with $\epsilon = 11.9$. The dielectric constant ($\epsilon = \epsilon' + i\epsilon''$) of the GST was measured experimentally using ellipsometry and annealed at various temperatures between 130 °C and 220 °C [14] and implemented in the numerical model.

The simulated transmission spectrum of the device is plotted in Fig. 1(d). One can observe a narrow transparency peak at around 178.5 THz with an amplitude as high as 83% between two resonance dips at around 177.7 THz and 179.2 THz, respectively, which is considered to be an EIT-like effect. Here, we investigate the EIT effect under the following conditions: the resonance frequencies of the two coupled sub-resonators (DR and CWRs) are nearly identical, with minor deviation [Fig. 1(b)]. When the two resonators are arrayed within one unit cell, an EIT-like transparency window appears in the transmission spectrum instead of the transmission dips of the DR and the CWRs. The validity of the underlying EIT effect is also demonstrated by an analytical model based on the

coupled oscillator theory [ref], which shows good agreement with the simulation [Fig. 1(d)]. Figure 1(c) shows the simulated transmission spectra of the device for different annealing temperatures and one can clearly observe that the transmission spectrum shifts to lower frequencies when increasing the annealing temperature.

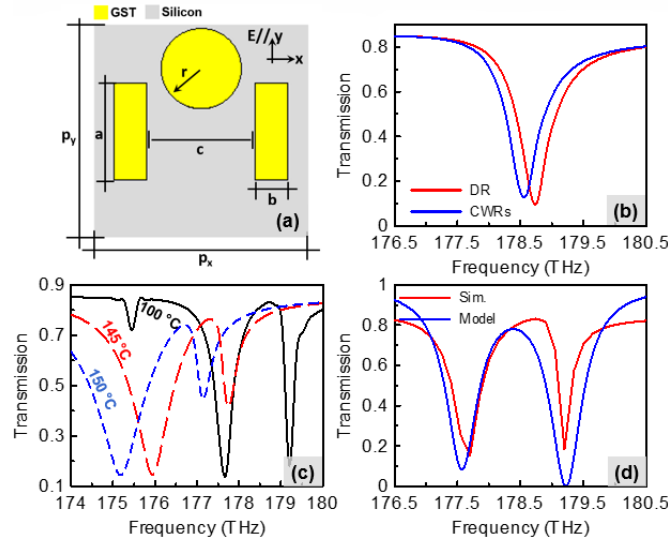


Fig. 1. (a) Unit cell of the designed metadvice with the corresponding electromagnetic excitation configuration. The relevant geometrical dimensions are: $p_x = p_y = 1 \mu\text{m}$, $a = 450 \text{ nm}$, $b = 150 \text{ nm}$, $c = 500 \text{ nm}$ and $r = 185 \text{ nm}$. (b) Simulated transmission spectra of the sole DR array and the sole CWR array. (c) Evolution of the simulated transmission spectra for different annealing temperatures. (d) Simulated (red line) and analytically fitted data (blue line) using the two-oscillator model.

3. Conclusion

In conclusion, we have demonstrated numerically and in the context of an analytical coupled oscillator model a frequency-agile EIT-like metadvice in the infrared regime. The frequency-tunability property of the proposed metadvice is performed due to the GST temperature-driven phase change material (PCM). Our results pave the way towards the development of compact delay lines and slow-light active metadevices.

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