High-sensitive and tunable terahertz metamaterial for polarization switch

Zhicheng Lin, Pengyu Liu, Zihao Liang, Xiao Zhang, Zefeng Xu, Zhi Zhang, 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: *A design of tunable terahertz (THz) resonator by using asymmetrical F-shape metamaterial (AFSM) is presented, which exhibits the switch function for single-band resonance at TM mode and dual-band resonance at TE mode.*
Keywords: *metamaterial, terahertz, switch, polarizer, modulator, resonator*

I. Introduction

Transformation optics is one of the key theories to describe the propagation path of electromagnetic wave [1]. Recently, terahertz (THz) metamaterial becomes a feasible material for electro-optics applications due to their unique optical properties that cannot be found in natural materials. There are many literatures reported THz metamaterials by using symmetrical or asymmetrical split-ring resonator (SRR) to perform THz filter, THz polarizer, and THz switch [2-4]. However, the resonant frequencies of these designs are unaltered, which can only filter or absorb certain electromagnetic spectra passively. To improve the flexibility of THz metamaterial, researches have been proposed and demonstrated many tuning mechanisms, including optical, electrical, magnetic, and thermal approaches [5-7]. These reported tuning mechanisms are limited to a single application caused from the symmetric or asymmetric SRR configurations. Therefore, the desire to achieve a multifunctional THz device with active tunability has been a research topic of interest for scientists.

In this study, we propose an active tuning mechanism to manipulate THz wave by using micro-electromechanical system (MEMS) technique. It has been widely used in the realization of movable microstructures and provides an ideal platform for the direct reconfiguration of metamaterials. The proposed device is a tunable THz resonator composed of asymmetrical F-shape metamaterial (AFSM). This design exhibits multi-functionalities and ultrahigh Q-factor. AFSM can be not only tuned from single-band to dual-band resonance at TE mode for filter and switch, but also tuned between TE and TM modes for polarizer. This design of MEMS-based tunable AFSM opens an avenue to the possibility of THz wave manipulations for the uses in filter, resonator, switch, and other THz applications.

II. Design and method

Fig. 1 shows the schematic drawing of MEMS-based tunable AFSM composed of an Au layer with 300 nm in thickness on silicon-on-insulator (SOI) substrate. The corresponding geometrical denotations of unit cell are illustrated, where P_x = 125 μm, P_y = 60 μm, a = 40 μm, c = 5 μm, d = 10 μm are kept as constant in this study. Three designs of AFSM are b = 60 μm, b = 65 μm, and b = 70 μm, respectively, while x parameter is changed from 0 μm to 40 μm. The resonant frequency of AFSM can be tuned by using MEMS-based actuation force to change x parameter, e.g. electrothermal or electrostatic force. The driving voltage can be applied on two pads for changing the distance between two F-shape microstructures, i.e. along x-direction. AFSM with gaps, i.e. x parameters between double F-shape microstructures can be considered as an inductive-capacitive (LC) resonator from the view of equivalent circuit. The inductance and capacitance are related to the contour and gap of AFSM, respectively. The electromagnetic resonance of AFSM is a function of refraction index of THz wave, according to the quasi-static formulas for a parallel plate capacitor and a solenoid. The inductance and capacitance in the formula can be expressed as $C = \varepsilon_0\varepsilon_c ct/x$ and $L = \mu_0 b^2/t$, where ε_0 is the free space permittivity, and ε_c is the relative permittivity of the materials within gap, t is the metallic thickness. Therefore, the resonant frequency of AFSM can be actively tuned to blue-shift by increasing x value.

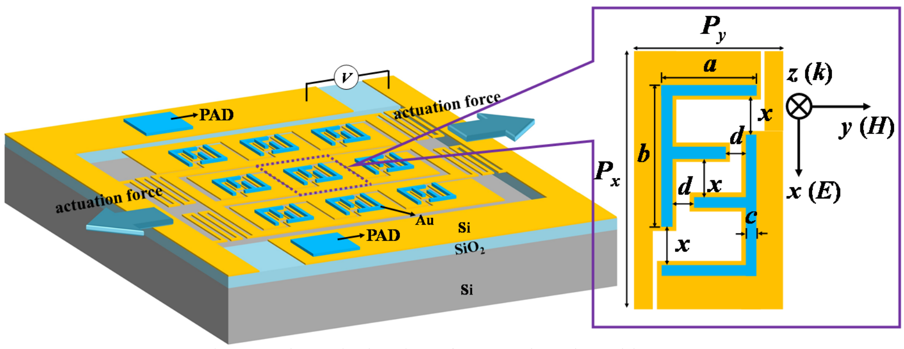

Fig. 1. Schematic drawing of MEMS-based tunable AFSM.

III. Results and Discussions

Fig. 2 shows the transmission spectra of AFSM by changing *x* parameter from 0 μm to 40 μm at TE and TM modes as shown in Fig. 2(a-c) and (d-f), respectively. In the initial state, the gap between AFSM is zero, i.e. *x* = 0 μm, the resonances of AFSM are 0.26 THz and 0.33 THz at TE mode and TM mode, respectively. When the device is applied a voltage to actuate AFSM, the *x* value can be changed from 4 μm to 40 μm. There are two resonances at TE mode. The first resonance is kept as constant as 0.21 THz and second resonance is shifted from 0.33 THz to 0.38 THz. The tuning range is 0.05 THz. It is clearly observed that AFSM exhibits a single-band and dual-band switching characteristic. At TM mode, there is one resonance shifted from 0.33 THz to 0.44 THz for *x* value changing from 0 μm to 40 μm. The trend of tuning resonance is nonlinear with a tuning range of 0.11THz. The relationships of resonances and *x* value for *b* = 60 μm, 65 μm, and 70 μm at TE and TM modes are plotted in Fig. 3(a) and (b), respectively. The resonance is blue-shift and then saturated gradually due to the F-shape microstructure is moved to be farer than another F-shape microstructure. The Q-factors and *x* values of MEMS-based tunable AFSM are plotted in Fig. 4. It is clearly observed the relationships of Q-factors and *x* values of three AFSM devices are linear trends. These Q-factors are almost identical and kept as constant as 45 at TM mode. At TE mode, the trends of Q-factors to *x* values of three AFSM devices are increasing gradually and similar linear trends as the fitting curves of green dash lines shown in Fig. 4. The corresponding slopes are 0.27, 0.30, and 0.42 for *b* = 60 μm, *b* = 65 μm, and *b* = 70 μm, respectively. The average Q-factors are 90, 83, and 93 for the cases of *b* = 60 μm, *b* = 65 μm, and *b* = 70 μm at TE mode, respectively. The highest Q-factor is 107 for the case of *b* = 70 μm and *x* = 40 μm. Such electromagnetic characteristic of ultra-high Q-factor is very suitable for the use in sensing application.

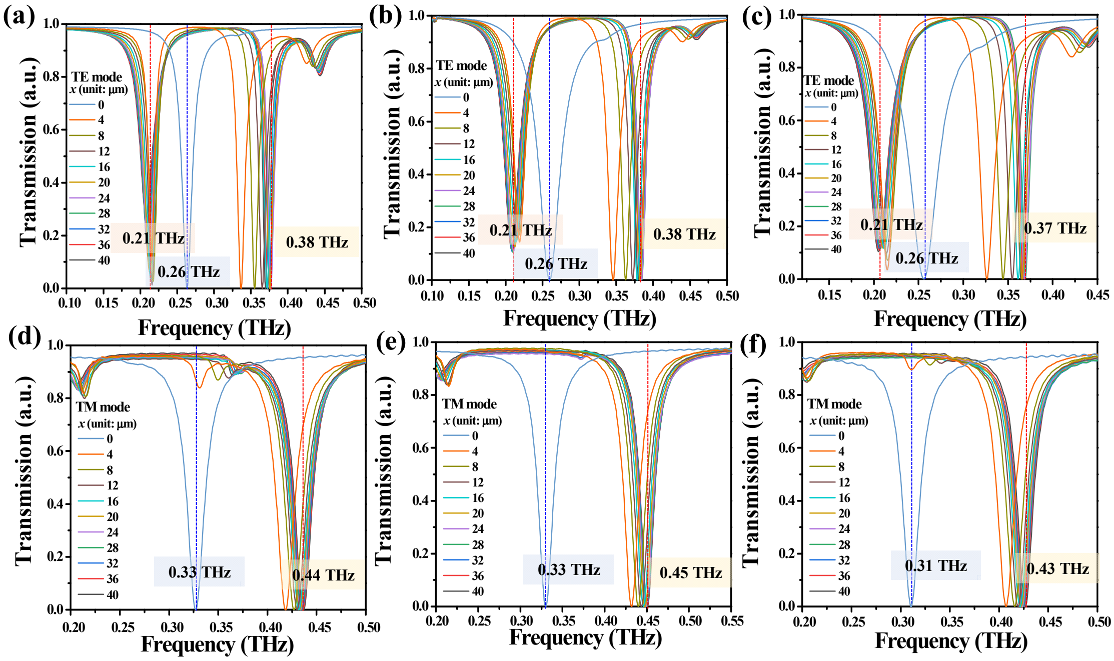

Fig. 2. Transmission spectra of AFSM with (a)(d) *b* = 60 μm, (b)(e) *b* = 65 μm, and (c)(f) *b* = 70 μm at (a-c) TE mode and (d-f) TM mode.

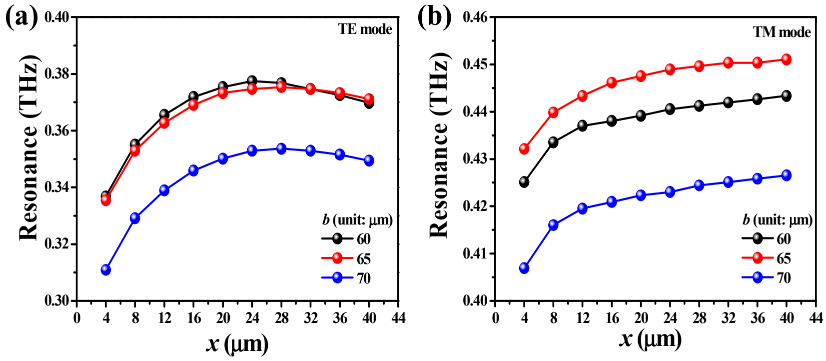

Fig. 3. The relationships of resonance and *x* value for *b* = 60 μm, 65 μm, and 70 μm at (a) TE mode and (b) TM mode, respectively.

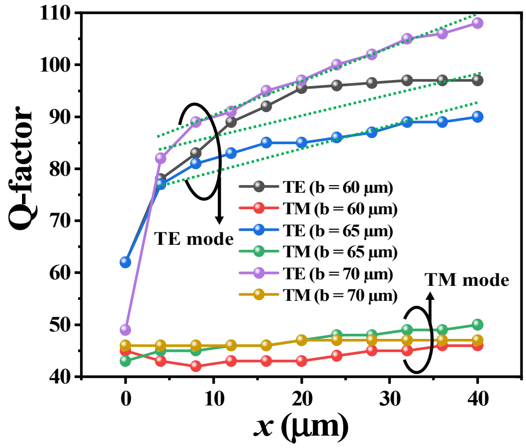

Fig. 4. The summaries of Q-factors for AFSM with different *b* value.

IV. Conclusions

In conclusion, an actively tunable MEM-based THz resonator by using AFSM microstructures is presented. The proposed AFSM device exhibits the tunabilities of single-band and dual-band resonances with an ultra-narrow bandwidth. The resonance could be tuned by changing the gap between F-shape microstructures. The tuning ranges of resonances could be spanned from 0.20 to 0.40 THz to be a THz switch function. The highest Q-factor is 107 for the case of $b = 70$ at TE mode. At TM mode, Q-factors of three AFSM devices are stable and kept as constant as 45. The proposed AFSM device can be not only realized an ultra-narrowband resonator but also a THz switch and polarization switch. This work provides the detail investigation of tunable THz resonator by using AFSM microstructures. With the investigation of geometrical relationships of AFSM being fully understood, the design of AFSM provides a new direction for future THz device applications.

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