Electromechanically Tunable Fishnet Metamaterial-based THz Filter

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Abstract

Engineered Terahertz (THz) filters are important because THz wave passes undetected through most of the naturally available materials. Therefore, this work presents an initial study, where a dynamic fishnet metamaterial based THz band-pass filter showing a tunability of ≈ 28 GHz/V around 8 THz has been designed. The reported tunability is achieved by electromechanically changing the dielectric constant between top and bottom metallic layers by cyclic variation of the input voltage from 0-9 V.

Introduction

- Terahertz waves (0.1- 10 THz)
  - Non-ionizing radiation – Biologically safer than X-rays
  - Passes through many optically opaque objects
  - Signature absorption of explosives, narcotics, protein and bio-molecules
- Applications – Security imaging, Explosive detection
- Problem – Lack of natural filters
- Solution – Engineered filters – Electromagnetic Metamaterials
- Fishnet metamaterials (FM) consist of dielectric layer sandwiched between two perforated metal layers.
- Negative index resonant frequency (f_{NI}) of FM depends on permittivity of dielectric layer sandwiched between two perforated metal layers.
- In this work, tunability of f_{NI} is achieved by changing the thickness of an air gap, inserted between top metallic layer and a static dielectric layer.

Design: Key Aspects

Objective

- Optimization of geometrical parameters to simultaneously satisfy the constraint imposed by electromagnetics and Microelectromechanical System (MEMS).
- $f_{NI} \cong 8$ THz

Commercial software used for:

- Electromagnetic simulation: Ansoft®
- MEMS simulation: IntelliSence®

Boundary conditions used in:

- Electromagnetic simulation
  - Wave ports at the top and the bottom of the unit cell for exciting and receiving the electromagnetic waves at normal incidence.
  - Periodic Boundary Condition (PBC) on the remaining four sides, as shown in Fig. 1(a).
- MEMS simulation
  - Bottom metallic layer is fixed and electrically grounded.

Materials used:

- Top and Bottom Metallic layers: Gold
- Static dielectric layer: Polydimethylsiloxane (PDMS)

- Optimized geometrical parameters are shown in Fig. 1(b) and 1(c).

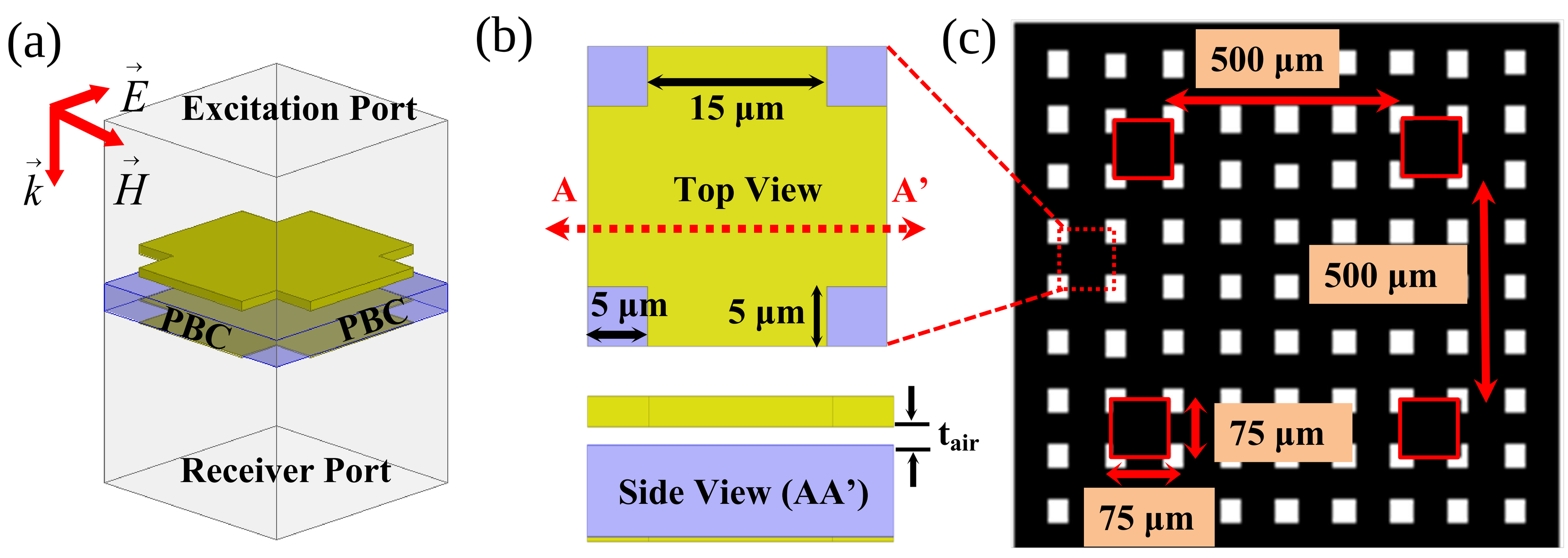

Figure 1: (a) Perspective view of unit cell of FM with boundary conditions used in electromagnetic simulation. (b) Top and Side view of a tunable FM unit cell along with geometrical dimensions. Thickness of air t_{air} = 0 - 2 µm. (c) Top view of repeating unit of top metallic layer with dimensions (not drawn to scale). Solid red boxes show the supporting pillars.

Electromagnetic Simulation: Results & Discussion

- Normalized transmission of the FM with the varying air thickness is shown in Fig. 2(a)
- In each transmission spectrum,
  - First peak (around 8 THz) is attributed to NI because at this frequency, the circulating current (flowing from top metallic layer-sandwiched dielectric-bottom metallic layer) opposes the incident magnetic field (as shown in Fig. 2(b)) .
  - Second peak (around 11 THz) is due to coupling of metallic wires in same layers.
- f_{NI} shows a significant non-linear blue shift (7.85 THz to 9.25 THz) with increase in air gap (0 µm to 2 µm), in contrast to the second peak .
- The peak shifted towards blue because f_{NI} depends inversely on the permittivity of dielectric layer (ref. Eq. 1) and with increase in the air gap average permittivity of sandwiched layer (air plus static dielectric layer) decreases.
- Increasing air gap beyond to 2 µm increases coupling losses between top and bottom metallic layer and pose the fabrication challenge.

$$f_{NI} = \frac{1}{\pi L\sqrt{\varepsilon_r \mu_r}}, \quad (1)$$

where L is the length of the unit cell, ε_r is the permittivity and μ_r the permeability of the sandwiched dielectric layer.

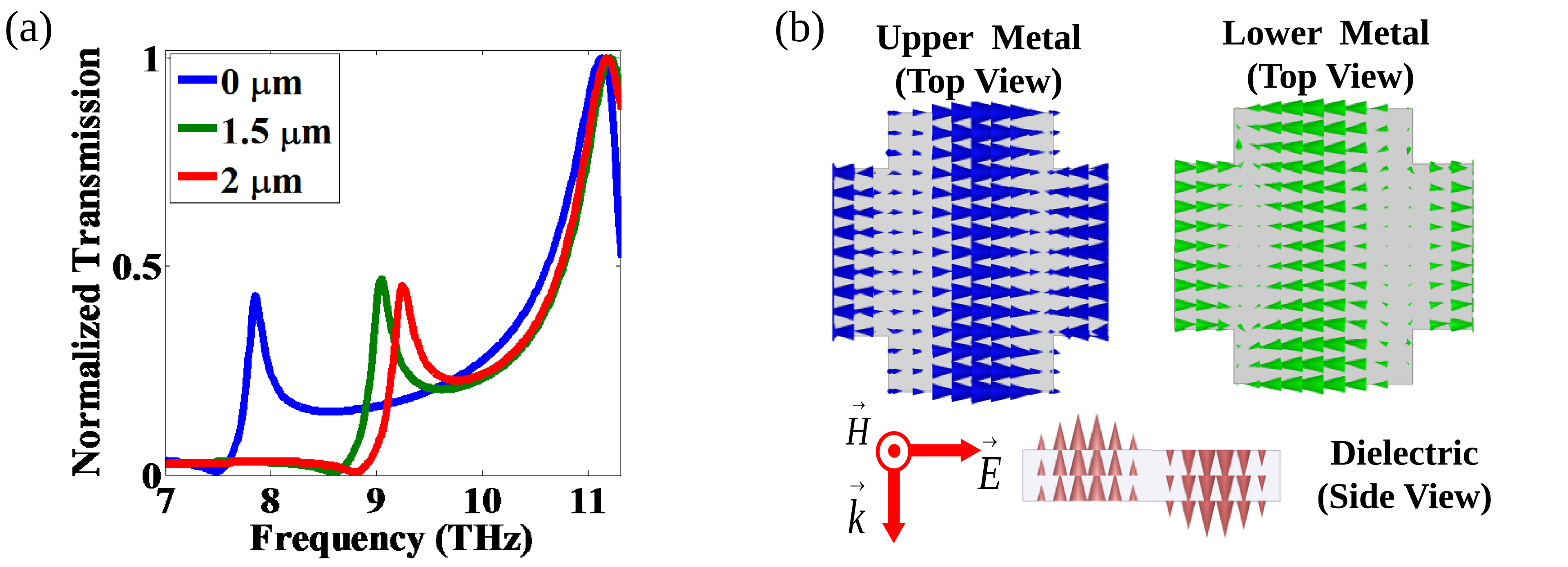

Figure 2: (a) Transmission characteristics of the FM showing shift in the negative peak with variation in the air gap thickness. (b) Instantaneous surface current and displacement current in top view of upper metallic layer, top view of lower metallic layer and side view of dielectric respectively at first peak.

MEMS Simulation: Results & Discussion

- The displacement of the top membrane as function of applied voltage across the top and bottom metallic layers is shown in Fig. 3(a).
- Pull-in voltage ≅ 9V.
- The cross-sectional & top view of the deformed top metallic layer at pull-in voltage is shown in Fig. 3(b) .

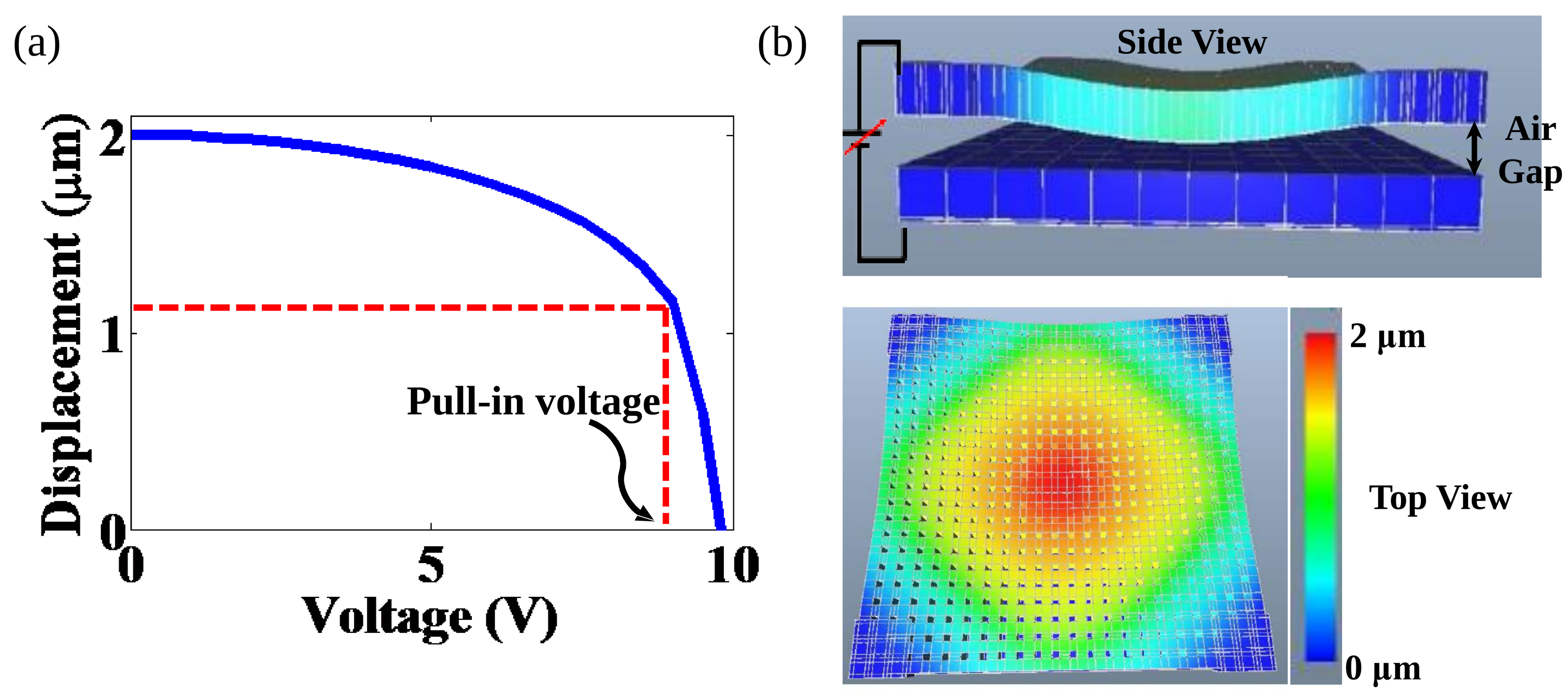

Figure 3: (a) Displacement versus Voltage graph showing pull-in voltage ≅ 9 V. (b) Side and top view of deformed membrane at pull-in voltage.

Conclusion and Future Work

In this initial study, through simulation, we have shown an electrically tunable THz filter by integrating NI fishnet metamaterial with electromechanical system. The designed filter shows a tunablity of ≈ 28 GHz/V around 8 THz. The 8 THz is selected for the ease of fabrication, i.e. for depositing and removing sacrificial layer, but the response of FM being scalable, the purposed technique can be used in entire THz range. The fabrication of the purposed filter is underway and will be reported in the near future. This dynamic band-pass filter will help to realize more compact THz based equipment for various applications such as explosives and narcotics detection.

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