# Time reversed lasing system for coherent perfect absorption based on switchable micromachined metamaterial mirrors

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**Abstract**

In this paper a time reversed lasing system for switchable coherent perfect absorption (CPA) is designed and demonstrated. The perfect absorption condition of the time reversed lasing is controlled by the micromachined metamaterial mirrors. In experiment, the peak absorption is measured to be larger than 97% which can be switched from 1.25 THz to 4.6 THz.

## 1. Introduction

Time reversed lasing is the counterpart to laser emission which refers to the absorption of one laser within a cavity contains the loss medium instead of the gain medium. This kind of absorption can be controlled by input another coherent laser beam into the loss cavity. The enhanced absorption within a low loss cavity has already been demonstrated by A. Douglas Stone et. al [1, 2]. Practically speaking, the coherent control lasers are not always available for an arbitrary input of the time reversed lasing system. Therefore, one port time reverse lasing systems using self-interference to control the absorption are more convenient for practically applications. Furthermore, tunability is another important parameter for narrow band absorption systems. In this paper, one-port time reversed lasing system with switchable metamaterial [3] is demonstrated to have a high absorption coefficient > 97% and lager tuning of the absorption frequency (> 200%).

## 2. Design of the Time Reversed Lasing System

The time reversed lasing systems are consisted of two micromachined metamaterial mirrors and a silicon substrate in between as shown in Fig. 1. The incident laser beam is input from one side of the cavity. The CPA effect arises from the interference between incident laser beam and reflected laser beam from the backside mirror within the cavity. The round trip absorption of the lasing cavity and phase change for certain wavelength can be controlled by the switchable metamaterial mirrors using micromachined actuators which make it a perfect candidate to control the CPA effect for arbitrary incidence. The unit cell of the switchable metamaterial mirrors is chosen to be asymmetric split ring resonator (ASRR) [4] which is shown in the insert of Fig. 1. The unit cell is consisted of two arcs one is larger and the other one is smaller. The phase and amplitude of the reflected laser beam by the backside mirror are determined by the coupling between the large arc and the small one. The side length of the ring $L$ is 25 μm and the width of the ring $W$ is 3 μm. The period of the unit cell $P$ is 30 μm. The initial gap between the large arc and small arc $G$ is 3.5 μm which means the small arc can be moved up 3.5 μm and connect to the large arc to form a closed ring (closed-ring state). Alternatively the small arc can be moved downward 3.5 μm to connect with the large arc at back side (back-touch state). The open state refers to the unit cell when there is no connection between the large and small arc.

 

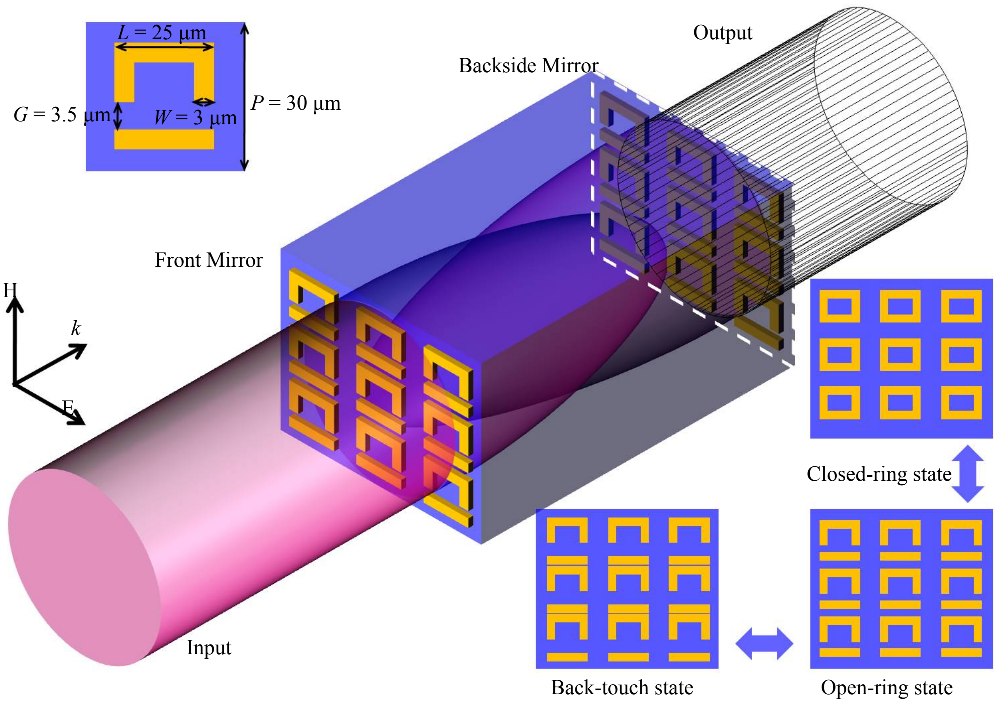


Figure 1: Schematic of the time reversed lasing system. The light is incident from one side of the metamaterial mirrors with the electric field parallel to the small arc.

## 3. Experimental Results and Discussions

For experimental studies, the tunable magnetic metamaterial is fabricated on a silicon-on-insulator (SOI) wafer using deep reactive ion etching (DRIE) processes [3]. Fig. 2 shows a portion of the micromachined metamaterial mirror using scanning electron microscopy. The metamaterial consists of 400 × 400 unit cells which indicate the mirror size is around 1.5 $cm^2$.

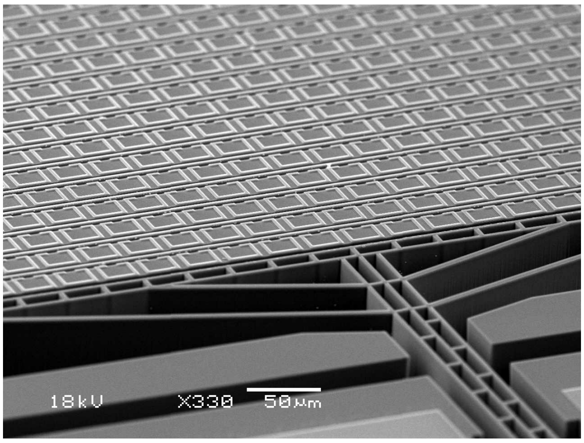


Figure 2: Scanning electron micrographs (SEM) of the fabricated micromachined metamaterial structure. Overview of the unit cell array with micromachined actuators.

The absorption of the time reversed lasing system is measured using a Bruker Vertex 80v Fourier transform infrared (FTIR) spectroscope. The absorption spectra from 1 THz to 4 THz at different mirror states (See Fig. 1 insert) are shown in Fig. 3 and the inserts shows the intensity of the surface current. For closed-ring state, the surface resonance is not very obvious at absorption peak frequency 4.6 THz. The absorption and wavelength selectivity of the mirror is trivial at this state. The absorption spectrum is similar to those of the two-port CPA systems [2]. However, in the open-ring and back-side state, the surface current is larger which results in high wavelength selectivity and absorption of the metamaterial mirrors. Therefore, the absorption peaks is not evenly distributed in the frequency domain due to the interference incidence and reflectance from the back side mirror which indicates a method to achieve single frequency absorption in large frequency region.

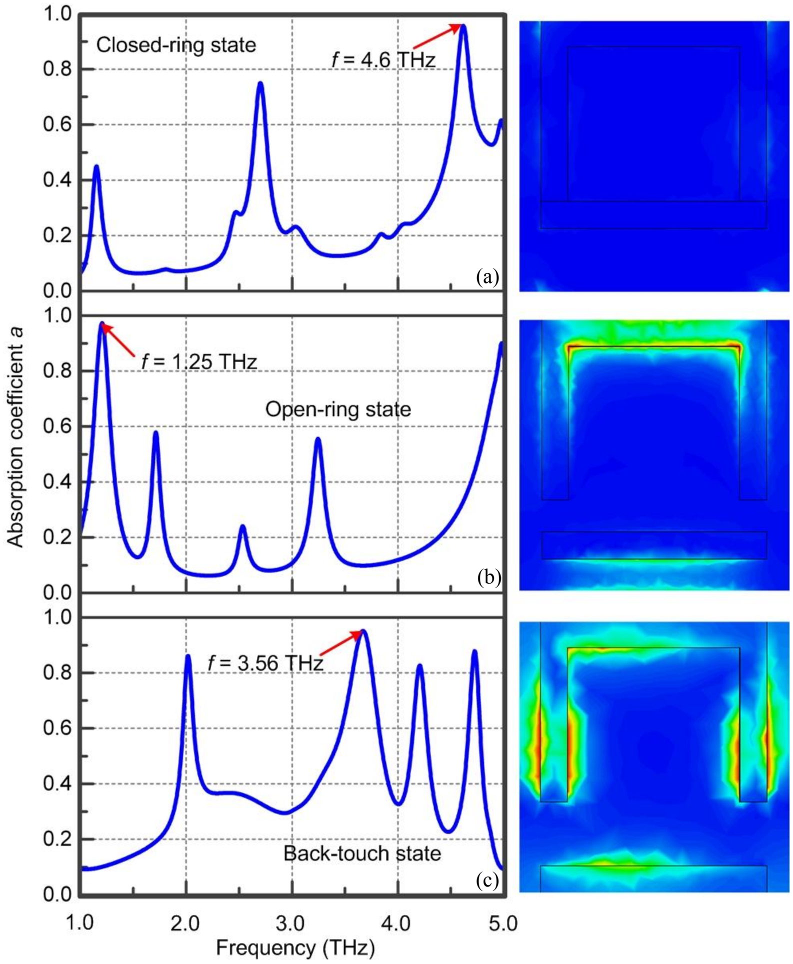


Figure 3: Absorption spectrum ate different states of metamterial mirrors: (a) closed-ring state, (b) open-ring state and (c) back-touch state. The inserts shows the distribution of surface current strength within the unit cell.

## 4. Conclusions

In conclusion, a time reversed lasing system for coherent perfect absorption is demonstrated using micromachined switchable metamaterials. In experiment, the peak absorption is measured to be larger than 97% which can be switched from 1.25 THz to 4.6 THz (> 200% of the initial absorption peak). The switchable time reversed lasing system has potential applications on detectors, transducers and switches.

## References


[1] W. Wan, Y. D. Chong, L. Ge, H. Noh, A. D. Stone and H. Cao, Time-reversed lasing and interferometric control of absorption, *Science*, vol. 331, p. 889, 2011.

[2] Y. D. Chong, L. Ge, H. Cao and A. D. Stone, Coherent perfect absorbers: time-reversed lasers, *Physical Review Letters,* vol. 105, p. 053901, 2010.

[3] W. M. Zhu, A. Q. Liu, X. M. Zhang, D. P. Tsai, T. Bourouina, J. H. Teng, X. H. Zhang, H. C. Guo, H. Tanoto, T. Mei, G. Q. Lo and D. L. Kwong, Switchable magnetic metamaterials using micromachining-processes, *Advanced Materials*, DOI: 10.1002/adma.201004341, 2011.

[4] N. I. Zheludev, The road ahead for metamaterials, *Science*, vol 328, p. 582, 2010