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Terahertz Metamaterial-Based Microbolometers Fabricated by Conventional MEMS

Tianhong Ao, Xiangdong Xu*, Yu Gu, Zhegeng Chen, Yadong Jiang*, Xinrong Li, Yuxiang Lian, Fu Wang, Qiong He

State Key Laboratory of Electronic Thin Films and Integrated Devices, School of Optoelectronic Information, University of Electronic Science and Technology of China (UESTC), Chengdu, China
Email: tianhong_ao@hotmail.com, *xdxu@uestc.edu.cn, *jiangyd@uestc.edu.cn

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Abstract

37 µm × 37 µm array of metamaterial-based microbolometers was designed and successfully fabricated by conventional MEMS technology. FTIR measurements reveal that the as-designed microbolometers exhibit a high absorption of ~31.5% at 3.93 THz. In contrast, no response can be detected from those microbolometers without metamaterials. The experimental results have been confirmed by simulations.

Keywords

Metamaterial, Absorber, MEMS, THz

1. Introduction

Recently, metamaterials (MMs) have attracted great attention owing to their outstanding electromagnetic properties as artificial functional materials [1]. A significant superiority of MMs over natural materials is that MMs can easily achieve desirable electromagnetic responses [2]. Applications of MMs in terahertz (THz) regime, a band range from 0.1 THz to 10 THz, provide new option to THz system including THz source, propagation, and detecting [3]-[5]. It is reported that well-designed MMs with Metal/Dielectric/Metal (MDM) sandwich structure can perform as perfect absorbers with nearly 100% absorption [6] [7]. On the other hand, the development of uncooled THz detectors is practically challenged, largely due to rather weak THz absorption of common functional materials and devices [8]. In order to solve this problem, we tried to fabricate MMs absorbers on microbolometers by conventional micro-electromechanical systems (MEMS) technology.

Generally, complete microbolometers consist of optical windows, read circuits, electrodes, thermistors, etc. In order to simplify the investigation, we focused on the mechanical and THz responses of the microbolometers, whose results would rightly reflect the complete devices. In this work, square-shaped MDM metamaterial absorbers were designed and fabricated on conventional microbolometers.

*Corresponding authors.

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2. Process for Fabrication of MM-Based Microbolometers

The fabrication process is illustrated in **Figure 1(a)**. In step 1, a 2 μm-thick polyimide was spun on a Si wafer. Apertures were etched to be open for follow-up piers. Then, a 300 nm-thick SiN_x film was deposited by plasma-enhanced chemical vapor deposition (PECVD) and serves as supporting layer for microbolometers. In step 2, a 100 nm-thick bottom aluminum (Al) film was deposited by electron beam evaporation. Subsequently, another 900 nm dielectric SiN_x film was deposited by PECVD again, serving as dielectric for metamaterials. After that, square-shaped dielectric layer was etched. In step 3, upper square Al was deposited and etched. At the same time, the bottom square Al was corroded. Finally, in step 4, microbridges were patterned. After the sacrificial layer polyimide had been released, MM-based microbolometers were yielded. SEM image in **Figure 1(b)** confirms successful fabrication of MM-based microbolometers by MEMS.

The MM-based microbolometers were fabricated as 37 μm × 37 μm array. **Figure 2(a)** shows the model of microbolometer structure, where a, b, a_1, and b_1 are 21 μm, 18 μm, 18 μm, and 15 μm, respectively. The thicknesses of SiN_x films as supporting and dielectric layers are described above. Firstly, we evaluated the mechanical stability of the as-designed microbolometers by ANSYS software. This was performed by simulating the effects of a residual stress (+300 MPa) on the deformation of bolometers. As shown in **Figure 2(b)**, the stress is concentrated on the corners of the microbridge, and thus the microbridge is moved for ~0.76 μm. It is worth noting that such deformation (~0.76 μm) is not bad enough to damage the microbridge, as proved by **Figure 1(b)**.

3. Simulation and Measurement Results

In this work, we pay special attention to the responses of the microbolometers in THz region. The THz responses of the MM-based microbolometers were first simulated by CST software. In the simulations, the refractive index (*n*, and $n = \sqrt{\varepsilon}$) of SiN_x is 1.98, and the conductivity of aluminum is 4.56×10^7 S/m. Simulations reveal that the absorption of the MM-based microbolometers is ~43.3% at 3.97 THz (**Figure 3**, blue line), but almost zero for those microbolometers without MMs (**Figure 3**, black line). In optical experiment, transmittance *T* and reflectance *R* can be measured, and the absorption A derives from A = 1 − T − R. It is worth noting that absorption of ~31.5% at a central frequency of 3.93 THz was experimentally measured by Fourier transform infrared spectroscopy (FTIR) (**Figure 3**, red line). Such THz absorption (~31.5%) is 1 - 2 order magnitude higher than those of the conventional microbomometers without MMs. Clearly, the experimental measurement agrees well with the simulated result (**Figure 3**), both of which demonstrate that the THz absorption of the microbolometer indeed can be significantly enhanced by the additional MMs. Such MM-based microbolometers with high THz absorption hold great potential for applications in THz detectors.

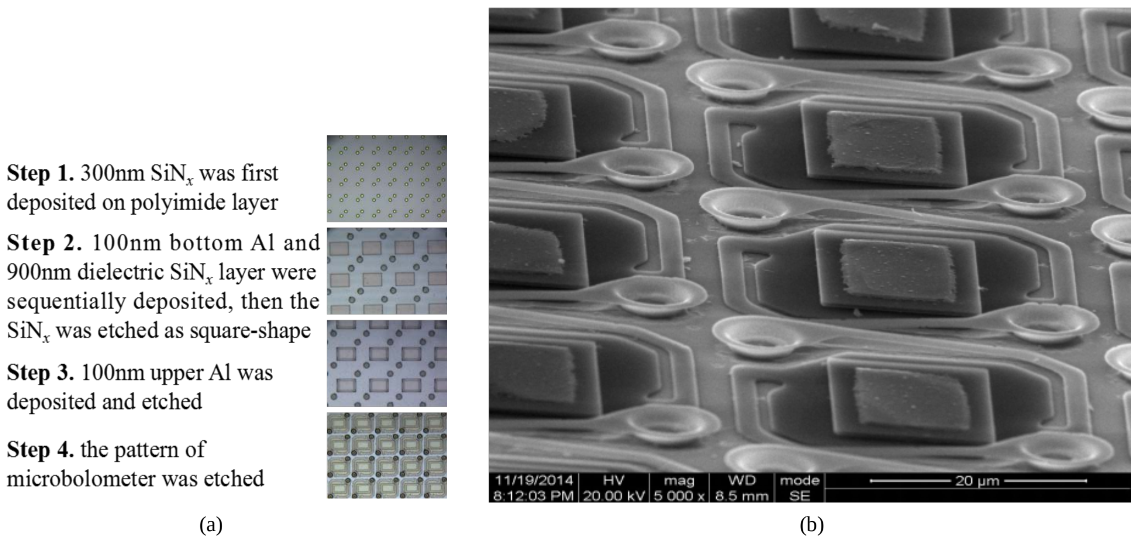
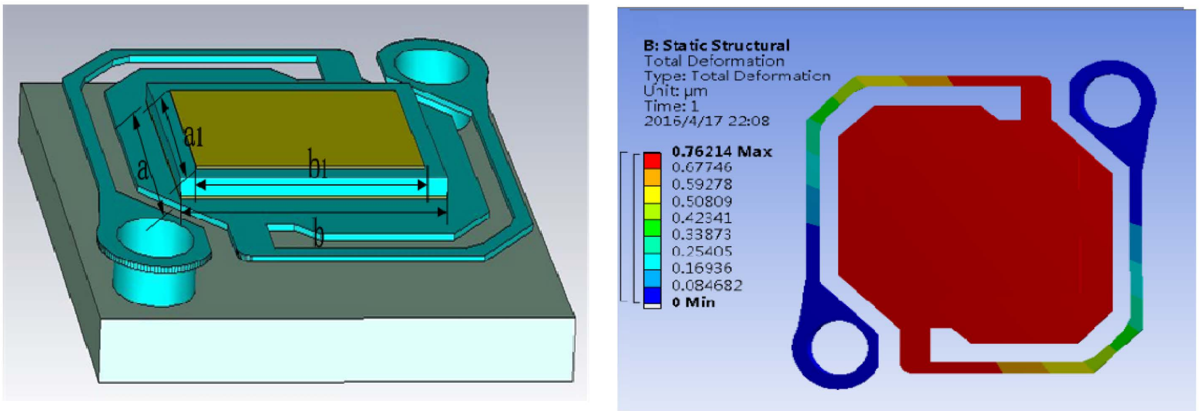


Figure 1. (a) The left indication shows the process steps for fabrication of MM-based microbolometers, the right pictures are the optical images for the sample after each steps, (b) the top view of SEM image of the as-fabricated array.



(a) (b)

Figure 2. (a) The model of microbolometers in simulation; (b) simulated deformation of the microbridge.

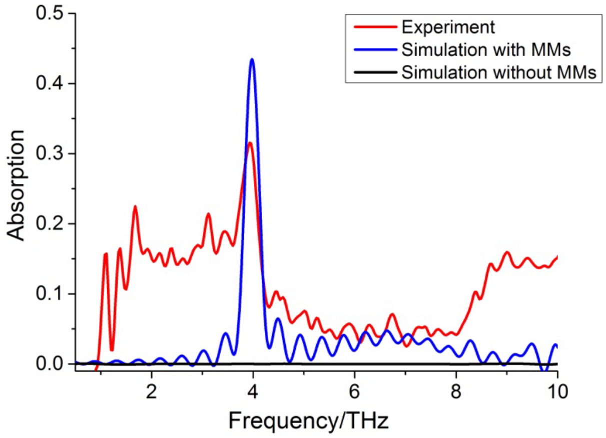


Figure 3. Experimental (FTIR) and simulated results of the microbolometers with and without MMs.

4. Conclusion

In summary, MM-based microbolometers were designed and successfully fabricated by conventional MEMS. Both simulation and experimental measurement demonstrate that the THz absorption of the microbolometers can be significantly enhanced by the additional MM absorbers. Our results will be helpful for the development of novel and efficient microbolometers for uncooled THz imaging.

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