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MEMS-Based Terahertz Detectors

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Abstract

A MEMS based novel THz detector structure is designed and realized by micro fabrication. The detector is then characterized to extract its mechanical performance. Operating in 1-5 THz band, the detector has a pixel size of 200 µm × 200 µm. Bimaterial suspension legs consist of Parylene-C and titanium, the pair of which provides a high mismatch in coefficients of thermal expansion. The pixel is a suspended Parylene-C structure having a 200 nm-thick titanium metallization. Operation principle relies on conversion of absorbed THz radiation into heat energy on the pixel. This increases the temperature of the free-standing microstructure that is thermally isolated from the substrate. The increase in temperature induces mechanical deflection due to bimaterial springs. The detector is designed to deliver a noise equivalent temperature difference (NETD) less than 500 mK and a refresh rate of 30Hz.

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Keywords: MEMS;Terahertz Technology;detectors;metamaterials;optical readout

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Overview

THz radiation covers the part of the electro-magnetic (EM) spectrum between the microwaves and infrared (IR), which corresponds to frequencies from 100GHz to 10THz [1]. It has attractive properties, which make it suitable for various applications such as spectroscopy, sensing and imaging [2-4]. THz radiation has non-ionizing nature, since THz photons do not carry sufficient energy to ionize an electron from an atom or molecule. Therefore, it does not cause any significant damage to human DNA, as do X-ray imaging techniques.

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Moreover, THz radiation has the ability of both penetrating most dry, non-metallic, non-polar materials and simultaneously resolving details, which overmatch the corresponding resolution from sensors operating in the microwave region of the spectrum [5]. THz radiation is attenuated in atmosphere because of water content. While this restricts its utilization in radio communication systems, applications such as medical imaging exploit THz band, relying on difference in absorptivity between normal and cancer cells [6]. While sensing in terahertz regime is flourishing, MEMS-based metamaterials have been presented for terahertz applications [7-8]. Variety of imaging and spectroscopy applications in terahertz band has been increasing rapidly including detection of explosives, surveillance and medical screening. MEMS-based thermo-mechanical detectors, operating in 1-5 THz band, are presented in this paper. Absorption of the incident THz wave is accomplished by metamaterials, which are patterned metallic features on a suspended pixel. Metamaterials are integrated to the detector and the need for exotic materials that exhibit high absorption in the terahertz regime is eliminated. The principle of operation of the proposed device can be summarized as follows. The absorbed THz radiation is converted to heat energy on the pixel. This causes an increase in the temperature of the released pixel that is thermally isolated from the substrate. The increase in temperature induces mechanical deflection due to suspensions made of materials with different coefficients of thermal expansion. The mechanical displacement of the pixel is read out by optical means.

1. Design of THz Detectors

The primary parts of the THz detector are an absorber, a supporting substrate, and a thermal connector. The absorber is designed to be large enough such that it adequately intercepts the incoming THz flux. The size of the detector, thus the absorber, scales with the wavelength of radiation when diffraction-limited optics is used to collect radiation. The geometry of metamaterial is optimized for high absorption in the targeted THz band. Thermal connector, linking the absorber and the substrate provides a very good thermal isolation thanks to the low thermal conductance (*G*) of the structural layer. However, as given by equation 1 below, there is a trade-off between the response time (τ_{th}) and the thermal conductance (*G*):

$$\tau_{th} = \frac{C}{G} \tag{1}$$

where *C* denotes the heat capacity. The geometry of the detector is optimized by a compromise between performance parameters of response time and Noise Equivalent Temperature Difference (NETD). A conceptual illustration of the THz detector with a side length of 200 µm is given in Fig. 1.

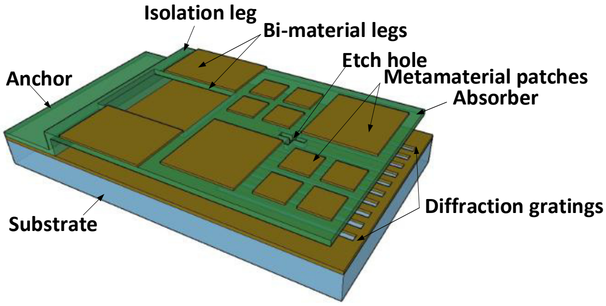

Fig. 1 Three-dimensional drawing of the detector structure.

The device consists of a released pixel, suspended to the substrate by a set of springs. Structural material for the device is a CVD-deposited layer of Parylene-C. The pixel carries metamaterial patch resonators providing resonant absorption at different frequencies for wide-band absorption. Displacement of the pixel is optically read out using an integrated diffraction grating interferometer that is defined using a diffraction grating underneath the movable structure. Thermally induced deflection of the device is predicted as 100 nm/K using finite-element simulations as shown in Fig. 2

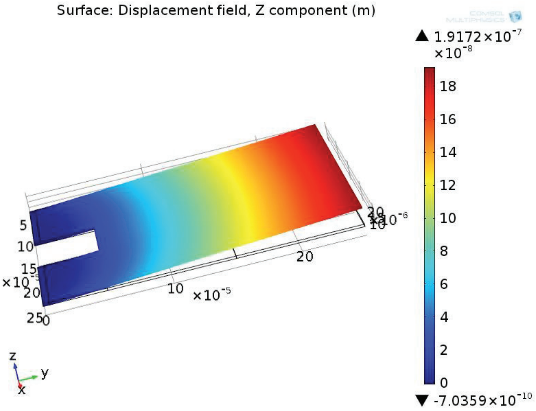

Fig. 2 FEM simulation of deflection behavior of the structure due to 1 K temperature difference.

2. Microfabrication of Detectors

Fabrication process uses four photomasks for lithographic definition. The process flow, given in Fig. 3, starts with a lift-off process to define a layer of 200 nm thick Ti in the form of a diffraction grating. Then, a 5 µm-thick photoresist layer is spun and patterned as a sacrificial layer, followed by deposition of a 2 µm-thick Parylene-C film, which is the structural layer. Next, a secondary Ti layer is sputtered for both bimaterial legs and the metamaterial absorbers. Thickness of the latter Ti film is chosen as 200 nm to yield a thickness ratio of 10:1 between Parylene-C and Ti to maximize the thermally induced deflection. HF wet etching is used for definition of the metallic structures. Finally, the detector is released by using acetone in critical point dryer to eliminate stiction problem. An SEM image of the fabricated samples is given in Fig. 4.

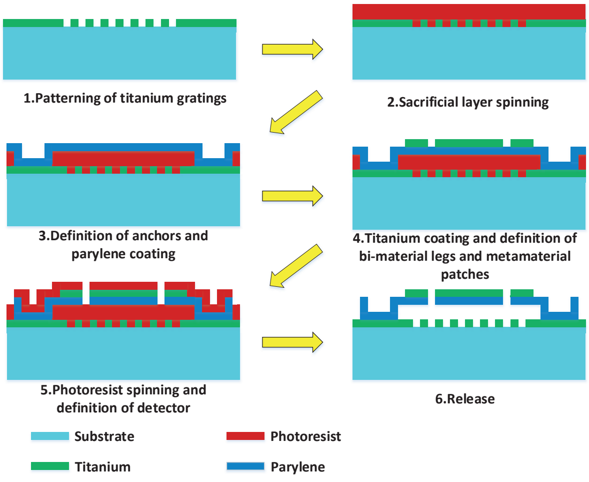

Fig. 3 Process sequence of the microfabrication.

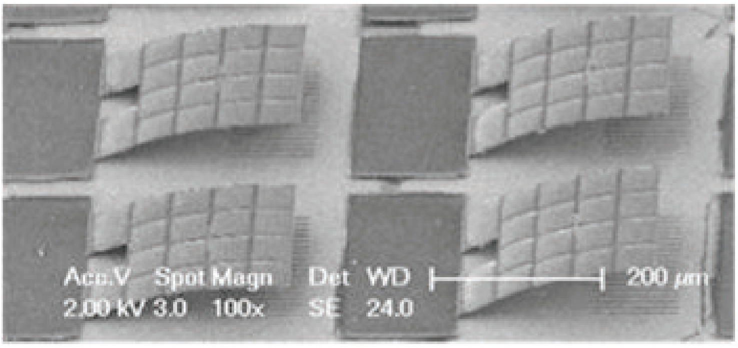

Fig. 4 SEM image of the fabricated devices.

3. Optical Readout

An experimental characterization setup, based on optical lever detection method, was built as shown in Fig. 5. A laser beam (λ=635 nm) was focused on an individual pixel structure using lenses L1, L2 and L3. The spot size of the laser beam on the plane of the detector was arranged to be 15 µm to ensure that the reflected beam was collected off of the mirror-like metamaterial patches. The last lens (L4) was used to focus the reflected beam on a segmented photodetector (PD). A Peltier thermo electric cooler (TEC) module with a temperature controller unit was used for the characterization of thermo-mechanical response. Fig. 6 shows the normalized deflections of two different pixels in comparison to a stationary reference on the chip when the temperature was swept between 18 and 40°C. Temperature change results in approximately 5-times larger optical signal on the devices as compared to the reference point.

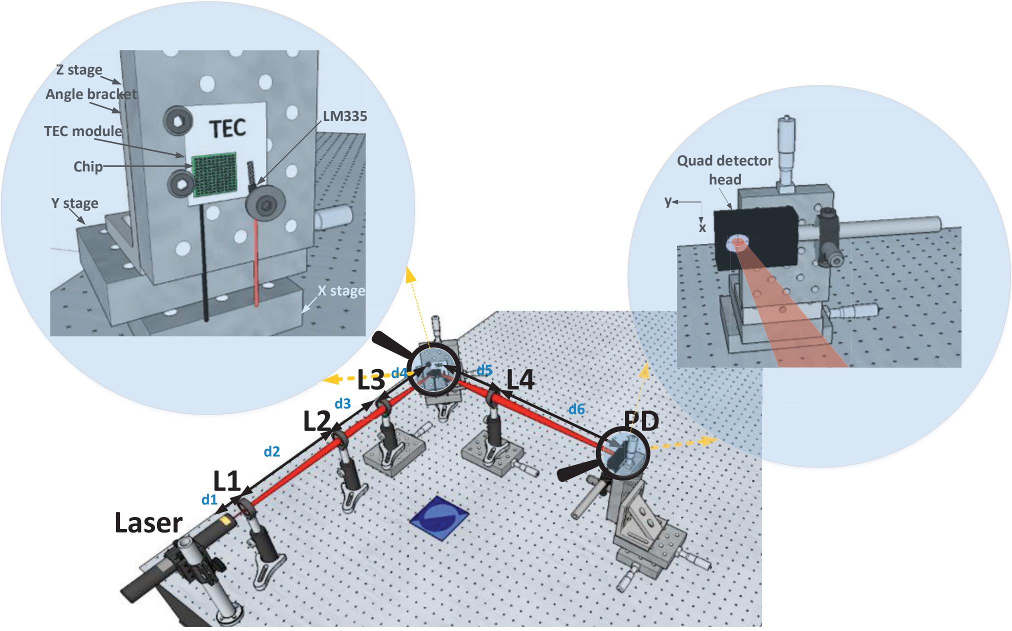

Fig. 5 Experimental characterization setup.

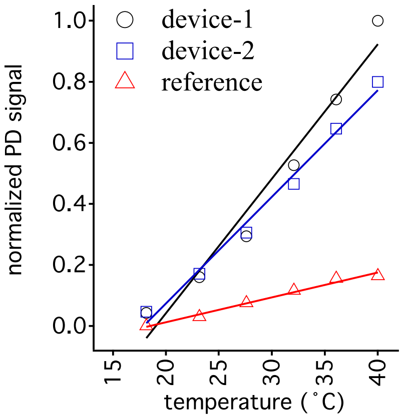

Fig. 6 Measured PD signal due to temperature difference.

4. Conclusion

A novel MEMS based THz detector is fabricated and initial characterization is performed. The device has a pixel size of 200 μm × 200 μm with an operation band 1-5 THz. Mechanical performance of the device is extracted and a linear tendency between the displacement and temperature is demonstrated. The device promises to deliver a noise equivalent temperature difference (NETD) less than 500 mK and a refresh rate of 30 Hz according to the theoretical and numerical calculations. The device is promising for spectroscopy and can be employed as a building block of an imager for security and medical applications. Future studies aim to implement an imager using a large-array focal-plane array comprising detector pixels.

Acknowledgements

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