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A MEMS-based terahertz detector with metamaterial-based absorber and optical interferometric readout☆

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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 0.5–2 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 detectivity (D*) of 2×10^9 cm $Hz^{-1/2}$/W and a refresh rate of 20 Hz.

1. Introduction

Terahertz band lies between microwave and infrared wavelengths, which corresponds to frequencies from 100 GHz to 10 THz in electromagnetic spectrum [1]. THz waves have unique properties, which make THz radiation suitable for various applications such as spectroscopy, sensing and imaging [2–4]. THz radiation has non-ionizing nature when compared to x-rays. Therefore, devices operating at THz frequencies are harmless to human beings and can be safely used for biomedical imaging purposes [5]. 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 [6]. Therefore, variety of imaging and spectroscopy applications in terahertz band has been increasing rapidly for security purposes including detection of explosives, surveillance or quality control purposes [2,7–12]. On the other hand, 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 [13–15]. High performance terahertz absorbers can help develop new devices for these applications. While sensing in terahertz regime is flourishing, metamaterials have been presented for terahertz applications [6,16–18]. Metamaterials are artificially engineered structures that exhibit unique properties such as negative values of index of refraction [19–21]. Metamaterial-based terahertz absorbers can absorb radiation close to unity at resonance and can be utilized to realize sensors and detectors [22,23]. The operating frequencies of metamaterials highly depend on their geometries. Thus, it is possible to design metamaterial-based absorbers for specific frequencies of interest.

In this paper, we present a MEMS-based thermo-mechanical detector, operating in 0.5–2 THz band. Absorption of the incident THz wave is accomplished by metamaterial-based absorbers, which are patterned metallic square patches on a suspended parylene pixel. Integration of simple metallic metamaterial structures to the detector eliminates the need for exotic materials that exhibit high absorption at the THz band. The suspended pixel is mounted on a substrate coated with a layer of metallic film. The metallic film on the substrate comprises grating structures underneath the suspended pixel. The gratings cover a portion of the pixel and are used for optical displacement readout of the suspended structure. The principle of operation of the proposed device can be summarized as follows. The absorbed THz radiation is converted to heat on the pixel. This causes an increase in the temperature of the released

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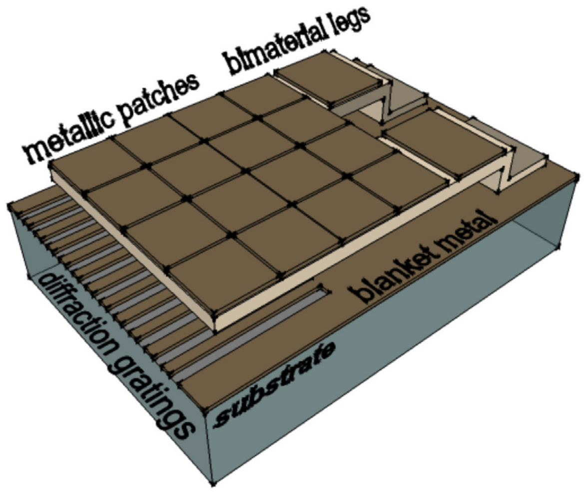

Fig. 1. Three-dimensional drawing of the detector structure. Please note that the figure is not drawn to scale. The suspended absorber that is 200 µm × 200 µm in size consists of 16 square patches of 43 µm × 43 µm, 2 bimaterial legs of 75 µm × 45 µm, and the bottom metallic layer on the substrate consists of 18 gratings with a size of 5 µm × 94 µm, each.

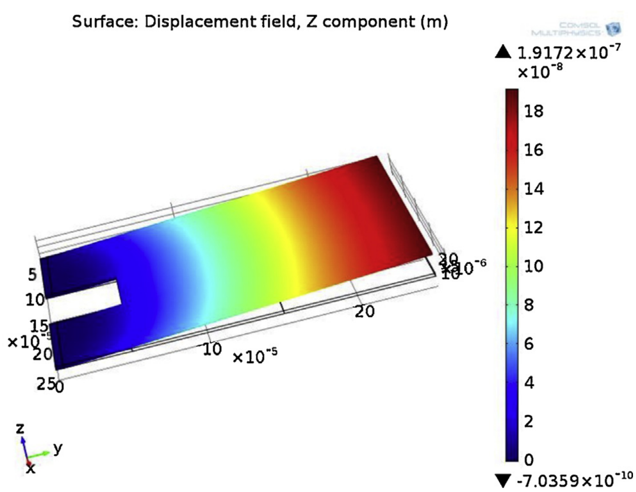

Fig. 2. FEM simulation of deflection behavior of the structure due to a 1 K temperature difference imposed on the detector.

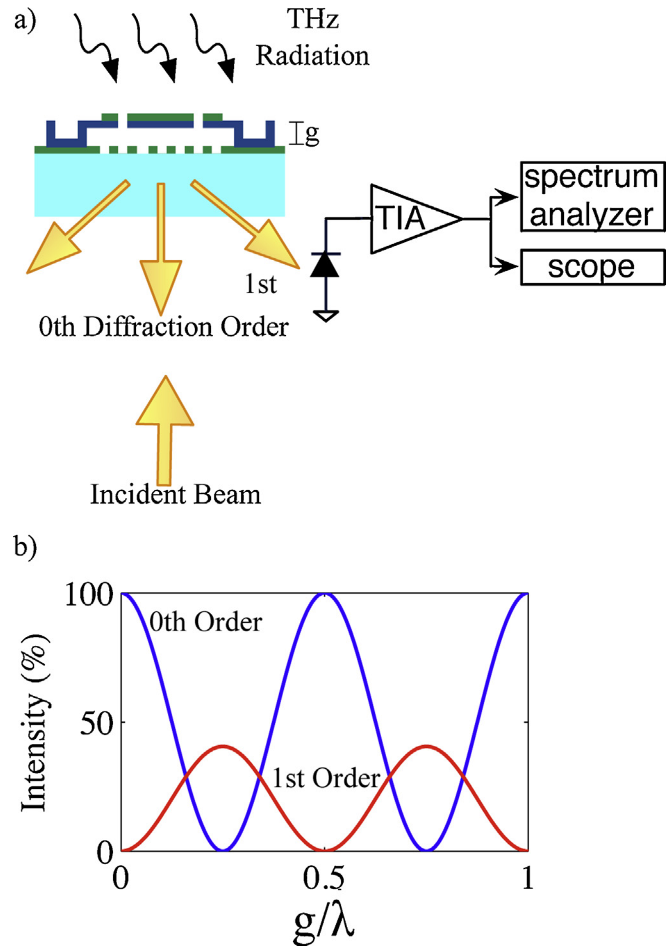

Fig. 3. (a) Schematics of the optical readout setup (b) expected normalized intensities of light in 0th and 1st diffraction orders as a function of gap height normalized to the wavelength of the readout beam.

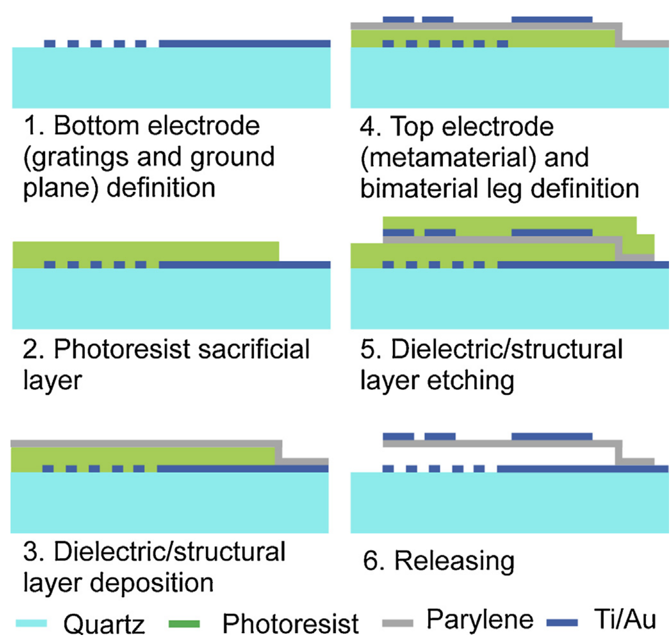

Fig. 4. Process sequence of the microfabrication. Please note that the figure is not drawn to scale.

pixel that is thermally isolated from its 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 using a diffraction grating interferometer, the method of which has been employed with thermomechanical infrared detectors [24,25]. Since the absorption characteristics of the detector is based on the geometrical properties of the metamaterials integrated to the suspended structure, it is feasible to realize broadband detectors with multiple patches with different geometries on a single pixel. On the other hand, it is also possible to design a detector that is sensitive to a narrow band of interest by integrating a single type of patches on the suspended structure. The readout principle is based on displacement detection by optical means. This is advantageous for thermomechanical detectors as electrically passive detectors can be designed. So, the thermal conductance of the detectors can be minimized since there is no need for electrically conductive layers that are also usually thermally conductive. In addition, electrically passive thermomechanical detectors do not suffer from Joule heating. We implement a diffraction grating interferometer for the readout, which has been demonstrated as