VIBRATIONAL IR MEMS SENSOR: APPLICATION OF TORSION-BARS TENSION- ENHANCED BY BIO-NANO CRYSTALLIZATION FOR HIGHLY SENSITIVE DETECTION

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ABSTRACT

A thin-film MEMS infrared (IR) sensor using torsional resonators was developed to achieve high sensitivity. The torsional resonators consisted of bimaterial; a tense Si thin-film and a metal film for IR absorption. Light incidence induced out-of-plane displacement of the resonators thereby shifting the resonant frequency of torsional vibration. To improve the response of the frequency shift, tension in the Si thin-film was enhanced by metal-induced lateral crystallization using biomineralized Ni nanoparticles and a lightweight metal was deposited onto the resonator to obtain flat profile. Response to heat and light incidence were discussed for the fabricated devices.

Keywords- MEMS sensor, IR, MILC

INTRODUCTION

Generally, there are two types of IR sensors; a quantum type and a thermal type. The quantum type is composed of semiconductor materials to transduce IR photons into electric carriers. Cooling is required to lower the thermal noise. The thermal type is composed of micro-/nano-structures to absorb IR photons. The absorbed IR photons locally heat up the structures. The temperature change is detected as IR incidence. The thermal type is not necessary to be cooled. However, improving the sensitivity is one of the remaining challenges for the thermal type sensor.

We had fabricated a thermal MEMS IR sensor that torsional resonators were applied to high sensitivity (Fig. 1) [1]. The torsional resonator consisted of bimaterial. A tense polycrystalline Si (poly-Si) film was used for the sensor body. A metal film (Au/Cr) was used for the IR absorber. When IR photons are absorbed, the resonator is bent upward due to difference in thermal expansion coefficients of the materials. The upward bending generates a hard spring effect in the torsion bars, increasing their resonant frequency. Because the frequency shift can be measured precisely, the torsional IR sensor could achieve high sensitivity.

The IR – frequency change depends on the bending displacement of the torsional resonator. The flat initial profile is necessary for high sensitivity. The flat profile is determined by the balance between the residual tensile stress in a resonator body (poly-Si) and the load by the deposited IR absorbing materials. The IR absorbing materials should be light-weighted and also have high absorbance for IR photons.

In this study, the sensor was fabricated by using a tense poly-Si film was obtained by metal-induced lateral crystallization (MILC) using biomineralized Ni nanoparticles (NPs), and light weighted materials of high coefficient of thermal expansion (CTE) and IR absorbance. The fabricated sensor was measured and characterized by heat and light incidence.

BIO-NANO CRYSTALLIZATION

When a hydrogenated amorphous silicon (*a*-Si:H) film is annealed, the incorporated H atoms are desorbed from the film, generating crystallization -induced tensile stress [2]. However, in the poly-Si film, there are many grain boundaries which do not contribute to generate the tensile stress. To increase the residual tensile stress, we have applied MILC using Ni NPs, biomineralized in *apoferritin* supramolecules, called “Bio-Nano Crystallization”. One of the advantages of using *apoferritin* supramolecules is homogeneous synthesis of NPs. The MILC uses a silicide reaction to initiate the crystallization at low temperature (550 °C) before the spontaneous crystallization starts in the *a*-Si:H film (600 °C) [3]. The grain sizes are increased, reducing grain boundaries. The residual tensile stress was measured 461 MPa [3].

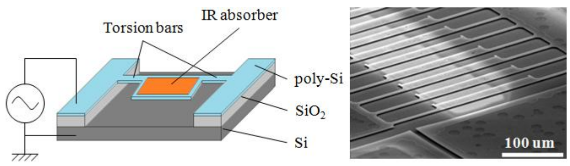

Figure 1. Schematic diagram of a vibration-type MEMS IR sensor (left) and SEM image of the fabricated device (right).

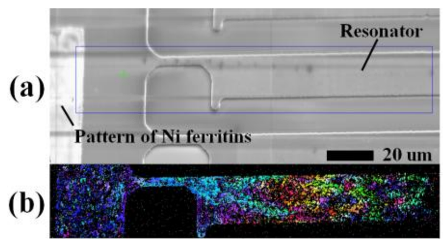

Figure 2. (a) SEM image of the fabricated resonators after MILC, and (b) EBSD image of the enclosed in (a). Crystallization is initiated from the Ni *ferritin* patterned area.

DEVICE FABRICATION

A *a*-Si:H film (~500 nm) was deposited on an oxidized Si substrate (SiO_2: 3 µm). B ions were implanted for electrical conduction. The structures of torsional resonators were patterned in the *a*-Si:H film layer by reactive ion etching. Then, the Ni NPs were adsorbed at the clamping ends of the torsion bars. During the MILC, the Ni silicides diffuse along the torsion bars. Electron backscatter diffraction (EBSD) imaging revealed uniformly crystallized torsion bars (Fig. 2). The resonators were further annealed (800 °C) to activate the implanted B ions. Subsequently, to release the resonator, an underlying oxide layer was etched by vapor-HF.

Through a stencil mask, Al film was deposited for the IR absorber and electrodes. Al has absorbance spectra for near infrared ray, and the CTE is 23.6 ppm/°C higher than those of Au (14.2 ppm/°C) and Cr (6.2 ppm/°C). Furthermore, a density of Al (2.7 g/cm^3) is lower than that of Au (19.3 g/cm^3) and Cr (7.2 g/cm^3). Therefore, for the initial profile of the torsion bars, a distortion by a metal film can be small.

RESULTS AND DISCUSSION

A cross-sectional profile of the resonator was measured with a white-light interferometer (Zygo NewView 7200) to observe the bending displacement to a substrate temperature. The resonator bent upwards with increasing substrate temperature (Fig. 3). This upward bending is one of the important factors that determine the sensitivity of IR detection. The deformation ratio of torsion bars, bent by the temperature, was evaluated to 1 nm/°C.

Response to the light incidence was measured by an optical method. Two red-lasers were used for heating the resonator and probing the torsional oscillation. The heating laser was irradiated onto the Al film as the IR absorber. The probing laser was irradiated onto the torsional resonators and reflected light was detected by a photo-diode. The detected signal was analyzed with a frequency response analyzer (NF, FRA 5097) (Fig. 4). The Q factor ranged from 80 to 170. The resonant frequency increases along with a power of the heating laser (Fig. 5). The resonant frequency shift ratio to a power density of heating laser was evaluated to be 300 Hz/(W/cm^2). When a power of the heating laser reaches at 3.6 W/cm^2, the resonant frequency is saturated, indicating the limit of the resonator bending. The actual IR detection should be conducted below the saturation.

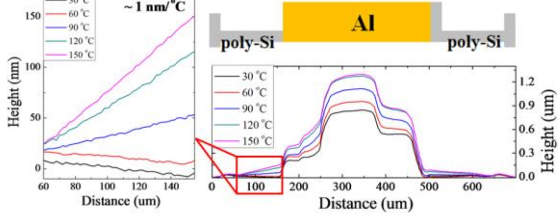

Figure 3. Cross-sectional profile of the resonator as a function of a substrate temperature.

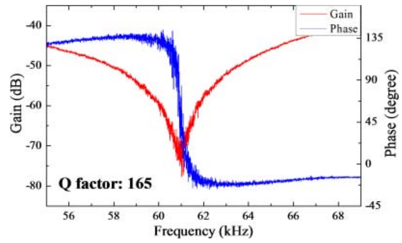

Figure 4. Resonant curves of the fabricated IR sensor.

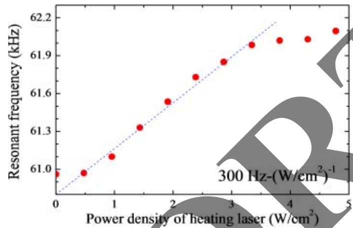

Figure 5. Changes of resonant frequencies as a function of a power density of a heating laser.

CONCLUSION

A novel IR sensor, which uses hard spring effect, was fabricated for high sensitivity. A tense poly-Si film by MILC and alight metal Al were used to make the initial resonator profile flat. Dependency of bending displacement on heating was evaluated to be 1 nm/°C. The bending displacement generated a hard spring effect on the torsion bars, which resulted in a resonant frequency increase. Optical response was confirmed by irradiating laser. Ratio of resonant frequency shift to a power density of the heating laser was 300 Hz/(W/cm^2).

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