ZERO-POWER LIGHT-ACTUATED MICROMECHANICAL RELAY

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ABSTRACT

This paper reports on the first demonstration of a passive light-actuated micromechanical relay (LMR). Differently from any existing switching element, the proposed LMR relies on a plasmonically-enhanced thermomechanical coupling to selectively harvest the impinging electromagnetic energy, in a specific spectral band of interest, and use it to mechanically create a conducting channel between the device terminals without the need of any additional power source, which directly translates into a near-zero standby power consumption. The first of a kind prototype presented here is selectively activated by an ultra-narrow band radiation in the mid-wavelength infrared (IR) spectral region (*~5.5 μm*). The strong and spectrally selective absorptivity (*~95%* at *5.5 μm* with a full width at half maximum of *~1.1 μm*) and the high thermomechanical coupling of the fabricated structure result in the first experimental demonstration of a LMR with an ultra-low actuation threshold of only *950 nW* suitable for the realization of a new class of zero-power IR digitizers capable of producing a quantized output bit in the presence of a unique IR spectral signature of interest.

INTRODUCTION

Due to the fast development of the Internet of Things, there is a growing need for unattended ground sensors that can remain dormant, with near-zero power consumption, until awoken by an external trigger or stimulus. Light-activated switches utilizing photodiodes, light-sensitive resistors or phototransistors [1] have been widely used for light sensing and light-controlled switching. However, they consume power continuously, regardless of the presence of the triggering radiation, which severely limits the sensors' lifetime. This work fundamentally breaks the paradigm of using active power to implement light-controlled ON/OFF switching while simultaneously achieving a large and abrupt change in conductivity (*~10* orders of magnitude), for sub-μW threshold values, which is not achievable with any of the existing technologies.

DEVICE DESIGN

The LMR consists of two symmetric released cantilevers facing each other as shown in Figures 1 and 2. Each cantilever is composed of a head, an inner pair of thermally sensitive bimaterial beams for actuation and an outer pair of identical bimaterial beams for temperature and stress compensation. The inner and outer beams are connected by a thermal isolation link. A lithographically defined near-perfect plasmonic absorber (Figures 1 and 2) [2, 3] is integrated in the head of one cantilever while the head of the other cantilever is covered by a *150 nm* gold reflector. The absorbing head carries a high stiffness bowl-shaped platinum tip electrically connected to one of the device terminals while the second terminal contact is defined on the opposite head and separated by a *~500 nm* air-gap (Figure 2). When IR radiation, matching the defined absorption band, impinges on the device from the top, it is exclusively absorbed by the plasmonic head, leading to a large and fast temperature increase of the corresponding cantilever up to the thermal isolation links (Figure 3) [4]. Such IR induced temperature rise results in a downward bending of the corresponding thermally sensitive pair of bimaterial beams (Figure 1b) and, therefore, in a vertical displacement of the platinum tip which is brought into contact with the opposite terminal when the absorbed IR power exceeds the designed threshold. Despite the intrinsically high sensitivity of the LMR to the absorbed radiation, the structure is completely immune to ambient temperature changes and residual stress thanks to the built-in compensation mechanism illustrated in Figure 1c.

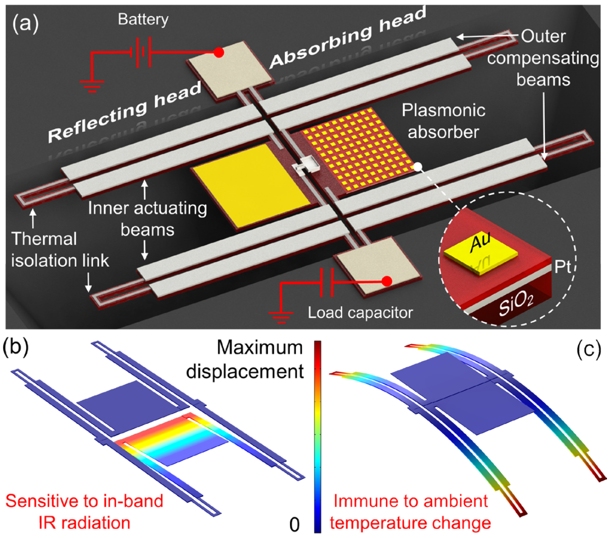

Figure 1: (a) Three dimensional (3D) mock-up of the LMR. (b) 3D finite element method (FEM) simulated deflection of the LMR in response to in-band IR radiation, selectively absorbed by the plasmonic head, and (c) under ambient temperature changes.

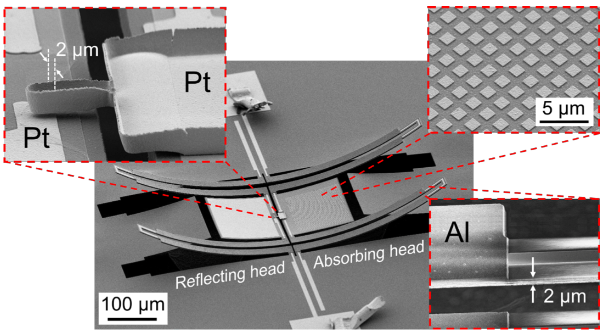

Figure 2: Scanned electron microscope images of a fabricated LMR. The beams are composed of 500 nm aluminum (Al) and 2 μm silicon dioxide (SiO_2).

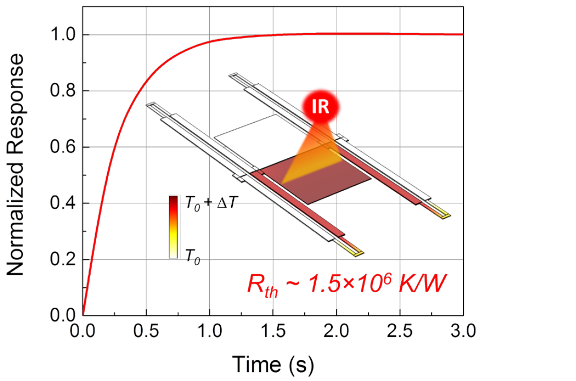

Figure 3: Thermal properties of the LMR evaluated by 3D FEM simulations. The inset shows the simulated temperature distribution of the LMR without a contact tip.

EXPERIMENTAL RESULTS

The absorption spectrum of the plasmonic absorber was measured by Fourier transform infrared (FTIR) spectrometer (Figure 4) showing a near-unity absorption *~95%* at *5.5 µm* with a full width at half maximum (FWHM) of *~1.1 µm*.

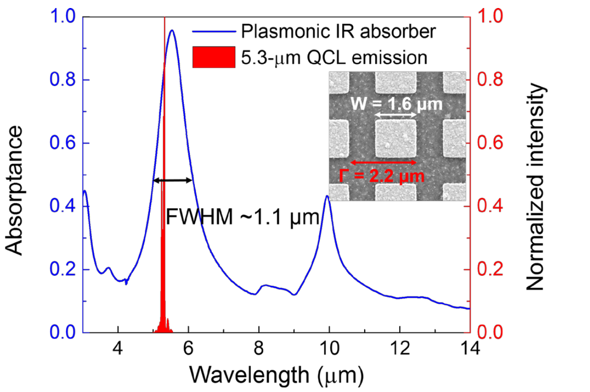

Figure 4: Absorption spectrum of the fabricated plasmonic head measured by a FTIR microscope.

The fabricated LMR was tested in a vacuum chamber with an IR-transparent window. A power-tunable *5.3-µm* quantum cascade laser (QCL) and the experimental setup illustrated in Figure 5 were used for testing. 5 reflective mirrors and a dichroic filter are properly set up to co-align a red laser beam with the QCL beam to facilitate the alignment with the sample (the red laser was OFF during IR testing). The beam spot (*~2 mm* in diameter) on the testing plane was characterized with a *100-µm* circular pinhole and a calibrated commercial thermal detector, showing a uniform power density at the center area of the beam. The LMR turned ON for an absorbed power of *950 nW* and turned OFF when the power was reduced to *520 nW* (Figure 6a). From this hysteresis, an ultra-low contact adhesion force of *5 nN* was extracted. The laser power was then kept constant at the found threshold value and it was mechanically chopped demonstrating reliable switching of the LMR for *100s* of cycles (Figure 6b). Such a large and abrupt change in conductivity, in response to sub-µW electromagnetic power, is not achievable with any of the existing light-controlled switching technologies.

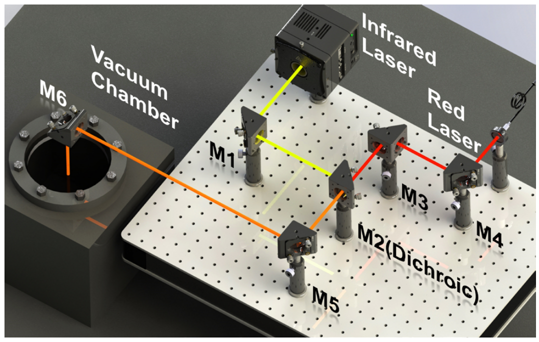

Figure 5: Experimental IR testing setup with QCL.

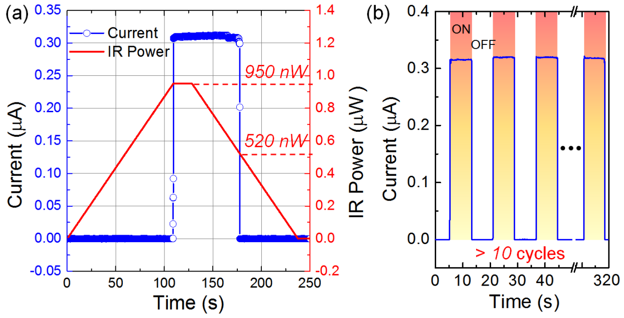

Figure 6: (a) Measured current through the LMR (for a 1 mV applied bias) while the power of the IR beam is gradually increased. The actuation power is estimated based on the calibrated power density and absorber area. (b) Measured current through the LMR in response to chopped threshold IR radiation. More than 10 consecutive ON/OFF cycles are recorded. The LMR was operated over 100 cycles without failure.

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