Observation of Tunable Opto-Mechanical Responsivity in Two-Dimensional Semiconducting Nanoelectromechanical Resonators

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***Abstract*— Nanoelectromechanical systems (NEMS) based on two-dimensional (2D) materials typically have motional parts that are atomically-thin, with displacement in the picometer range or even smaller. When measuring the nanomechanical device motion, a key challenge is to optimize the signal transduction efficiency (responsivity) in order to best detect the infinitesimal motion. Here we demonstrate tuning of the responsivity in optically-transduced atomically-thin NEMS resonators, by controlling the device deflection and thus profiles, and demonstrate the importance of optimizing the measurement condition.**

Keywords—Optical Interferometry; Nanoelectromechanical Resonators; MoS2; Responsivity; Tuning.

I. Introduction

2D NEMS resonators have ultralow power consumption, large frequency tuning range, and high sensitivity, making them promising for sensing and radio-frequency signal processing [1]. Yet the challenges for measuring the infinitesimal motion in minuscule 2D NEMS resonators often require researchers to optimize the motional signal transduction efficiency, *i.e.*, responsivity, in order for the mechanical displacement to be successfully measured [2]. Previous work has achieved measurement of resonances in 2D membranes using optical interferometry [3], but the transduction efficiency has not been deliberately tuned, and under most measurement conditions the responsivity is typically not optimized. In this work, we study the tuning of opto-mechanical responsivity with laser position and gate voltage, towards optimizing the motional transduction efficiency of 2D NEMS resonators.

II. Methods

We study the tuning of responsivity using a custom-built 2D NEMS resonator measurement system, including optical components for laser interferometry, a vacuum chamber to keep the device in ~1×10^{-6} Torr environment, an x–y stage with precise position control, and electrical connections for gate tuning and driving (Fig. 1a). The molybdenum disulfide (MoS_2) NEMS resonator (Fig. 1b) is fabricated using a previously established dry transfer method [4].

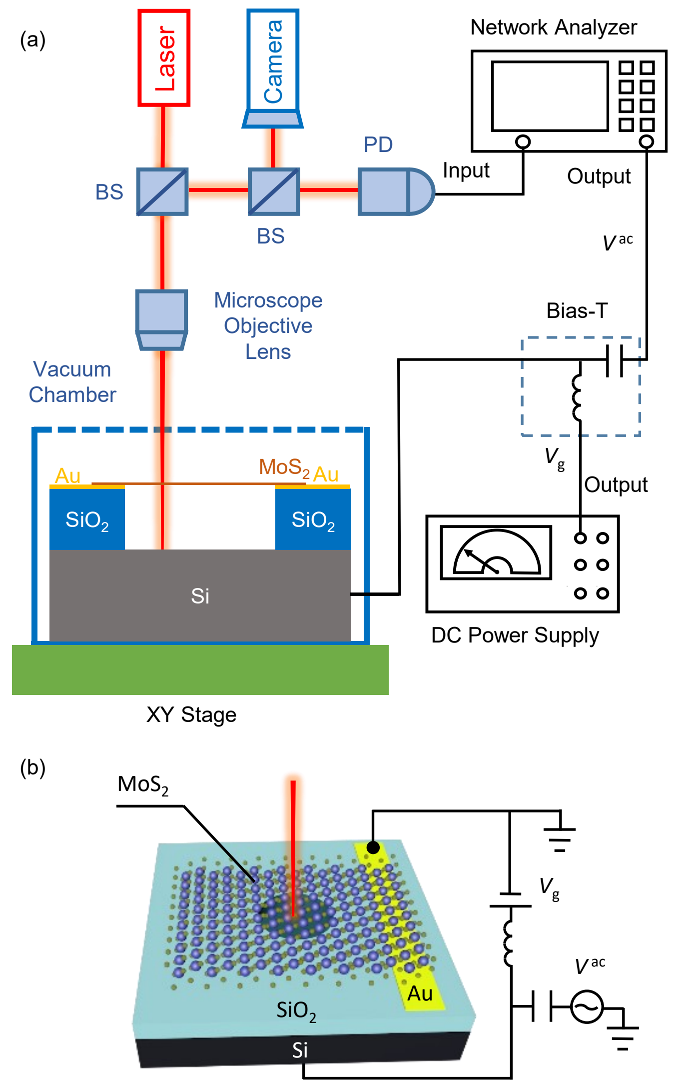

Fig. 1. Measurement setup and MoS_2 drumhead resonator device structure. (a) Schematic of the optical interferometry measurement setup. (b) Schematic illustration of the MoS_2 resonator actuated capacitively through the Si back gate electrode.

The resonator is actuated capacitively through its Si back gate electrode, using the AC output from a network analyzer in combination with the DC output from a power supply. As the laser is incident on the device, the reflected light intensity varies with the position of the MoS_2 flake, resulting from optical interferometry. The reflected light intensity is converted to electrical signal through the photodetector, and then measured by the network analyzer. Particularly, the interferometric condition changes when the MoS_2 membrane is deflected electrostatically (Fig. 2), and varies with the position of the laser spot (Figs. 3-5) due to the device deflection profile.

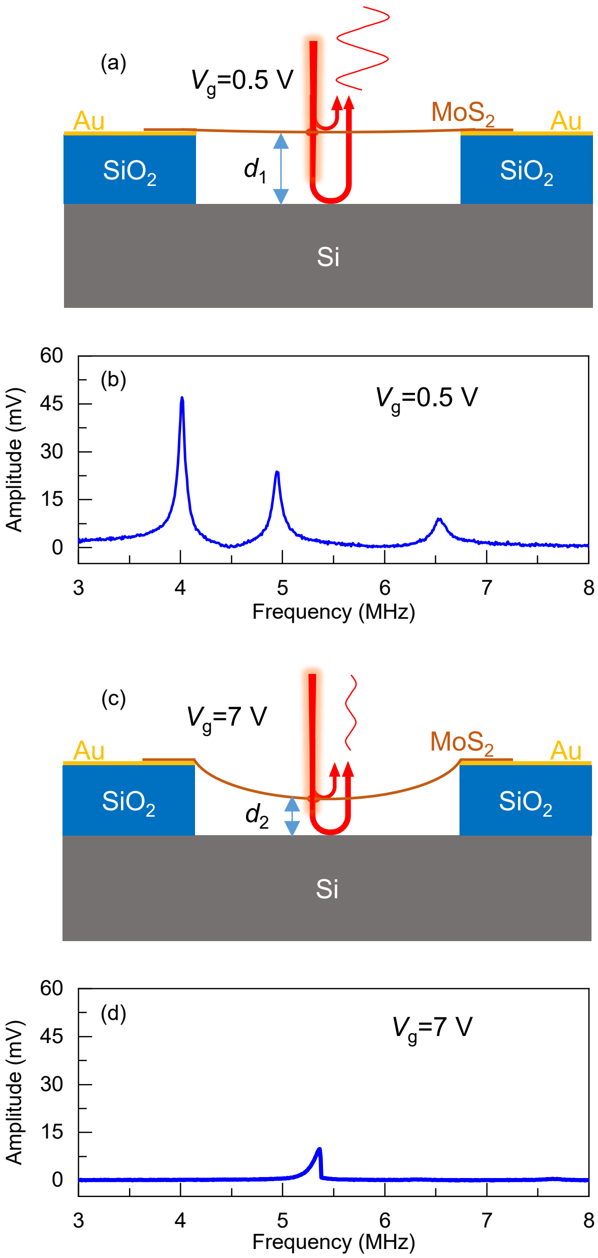

Fig. 2. Illustration of the gate tuning effect on interferometry responsivity and measurement data of the MoS_2 resonator. (a) Cross section of the device, showing the vacuum gap at 0.5 V gate voltage (V_g), and (b) corresponding resonance data. (c-d) Same as (a-b) but with 7 V gate voltage.

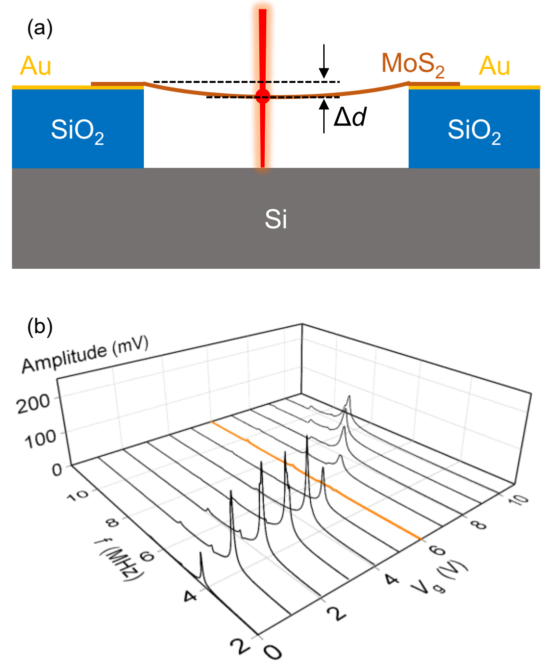

Fig. 3. Visualizing the responsivity change with gate voltage, with the laser spot at the center of the MoS_2 resonator. (a) Schematic showing the laser position. (b) resonance curves for 0–10 V gate voltages. The orange trace in the line plot indicate where the responsivity is zero, *i.e.*, the device motion can be hardly measured.

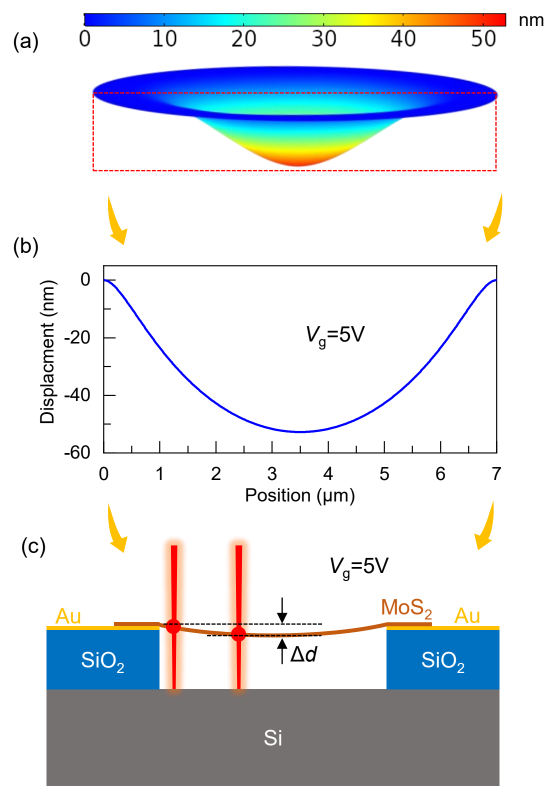

Fig. 4. Illustration of laser location effect on interferometry responsivity. (a) Finite element simulation of the MoS_2 resonator deflection under 5 V gate voltage (V_g). The device is a drumhead resonator with a radius of 7 μm. (b) Deflection profile of the device in the red dashed box in (a). (c) Illustration of location effect on responsivity.

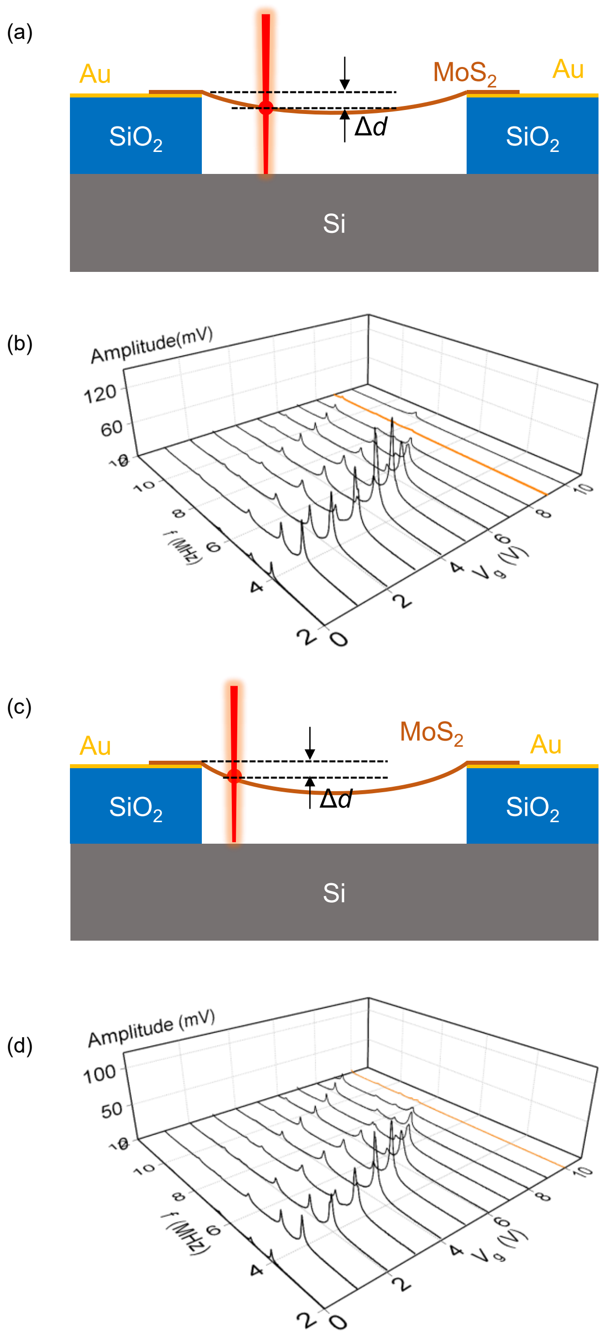

Fig. 5. Tuning and visualizing the responsivity, by moving the laser spot (a-b) away from the center, and (c-d) at the edge of the MoS_2 resonator. With the change of laser spot position, the voltage for 0 responsivity changes significantly.

III. Results

When DC gate voltage (V_g) is applied, the electrostatic force pulls down the MoS_2, which changes the interferometry condition and tunes the reflected light intensity. For the same MoS_2 resonator under V_g = 0.5 V and 7 V, the resonance signal amplitudes are clearly different, indicating a change in responsivity (Fig. 2). When the gate voltage varies from -10 V to 10 V, we observe the striking feature of 0 responsivity: at certain gate voltage (~ ± 6 V), the resonant signal becomes unmeasurable, as the responsivity crosses 0 point (Fig. 3). We further estimate the profile of the MoS_2 NEMS resonator under 5 V gate voltage using finite element simulation (Fig. 4). We confirm that the 0 responsivity we observed is due to the change in interferometric condition, rather than variation in actual device motional amplitude, by measuring the same device, under the exact same excitation amplitude and gate voltages, but at different laser spot positions. Fig. 5 clearly shows that as the laser spot moves, the interferometric condition changes due to different vacuum gap size, and the zero responsivity condition is met at different gate voltages (the orange trace in the line plot). These results clearly demonstrate the importance of laser spot position and gate voltage on the responsivity of 2D NEMS resonators.

IV. Conclusions

Our work clearly demonstrate that the optical interferometry signal transduction efficiency (responsivity) for measuring 2D NEMS resonators can be tuned by a number of parameters, such as laser spot position and gate voltage. Our results provide important guidelines for optimizing the transduction efficiency of NEMS resonances.

Acknowledgment

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