Frequency Tuning in Resonant Nano-Electromechanical Devices Based on Anisotropic Two-Dimensional Semiconductor Rhenium Disulfide

Fei Xiao, Bo Xu, Yachun Liang, Jiankai Zhu, Shenghai Pei, Ting Wen, Jing Li, Song Wu, Xia Juan, Zenghui Wang
University of Electronic Science and Technology of China, Chengdu, China

***Abstract*—We demonstrate NEMS resonators based on anisotropic 2D semiconductor ReS_2. The devices exhibit clear, electrically tunable mechanical resonances under both optothermal and electrostatic excitations, with frequency tuning range exceeding 100%. Our finding enables exploration of interplay between mechanical anisotropy and resonant responses in these atomically-thin semiconductors.**

Keywords—resonator; NEMS; frequency tuning; 2D material; anisotropy

I. Introduction

Rhenium disulfide (ReS_2) is a two-dimensional (2D) layered semiconductor belonging to the group 7 transition metal dichalcogenides (TMDC) [1]. Its unique in-plane atomic structure (Figs. 1a-b) gives rise to anisotropy in its physical properties [2]. Such anisotropy can be leveraged to realize novel resonator designs [3], as demonstrated in black phosphorus (P) nanoelectromechanical (NEMS) devices [4,5].

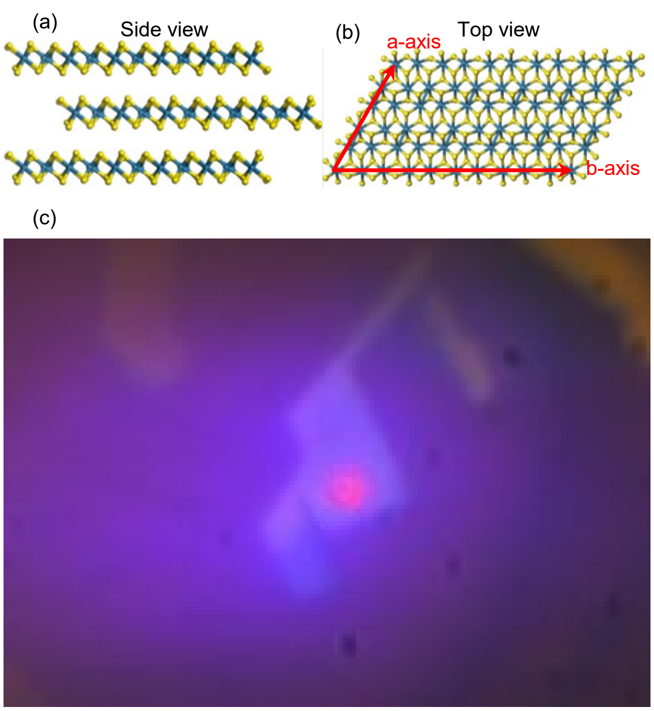

Fig. 1. Crystal structure of ReS_2. (a-b) Side and top views of the atomic structure. (c) Optical characterization of an ReS_2 flake, with the laser spot visible.

Compared with black P crystals which tends to degrade in ambient conditions [6], ReS_2 is more stable and thus better suited for certain device applications. More importantly, unlike monoatomic black P, the diatomic ReS_2 structure is expected to exhibit both piezoelectricity [7] and piezoresistivity [8], both of which are highly desirable for facilitating signal transduction in NEMS resonators.

Here we demonstrate resonance excitation, detection, and frequency tuning in ReS_2 NEMS resonators. By combining RF excitation signal and DC tuning voltage on the same gate electrode, we show that nanomechanical resonance can be efficiently excited and continuously tuned, with frequency tuning range over 100%, in these anisotropic 2D semiconducting devices, enabling detailed exploration of the coupling between its anisotropy and resonant responses.

II. Methods/Results

The ReS_2 NEMS resonators are fabricated using a dry transfer method [9], with electrical lead connecting to the ReS_2 flake produced by evaporation through a stencil mask. Once the device structure is determined, we first characterize its anisotropy and identify the crystal orientations. The Raman spectra measured with different polarization for a ReS_2 resonator device (Figs. 2a-b) clearly shows the anisotropy of the device.

We characterize the resonant response using an optical scheme [5], with the measurement setup shown in Fig. 3a: a modulated 405 nm laser excites the nanomechanical motion through optothermal effect, and a 633 nm laser detects the device motion interferometrically. The device exhibit clear resonant responses in the MHz range (Fig. 3b). We then examine the device performance using electrical excitation scheme (Fig. 4a), by applying the RF signal to the gate electrode underneath the device, with the resonant response shown in Fig. 4b.

We further explore gate tuning of the ReS_2 NEMS resonators for both optical and electrical driving schemes (Figs 3c and 4c). By applying a DC gate bias, we observe in both cases that the electrostatic tensioning effect dominates (over capacitive softening), with resonance frequency mostly increase with DC gate voltage magnitude (only the positive half is shown), and tuning range exceeding 100% (in the electrical driving case).

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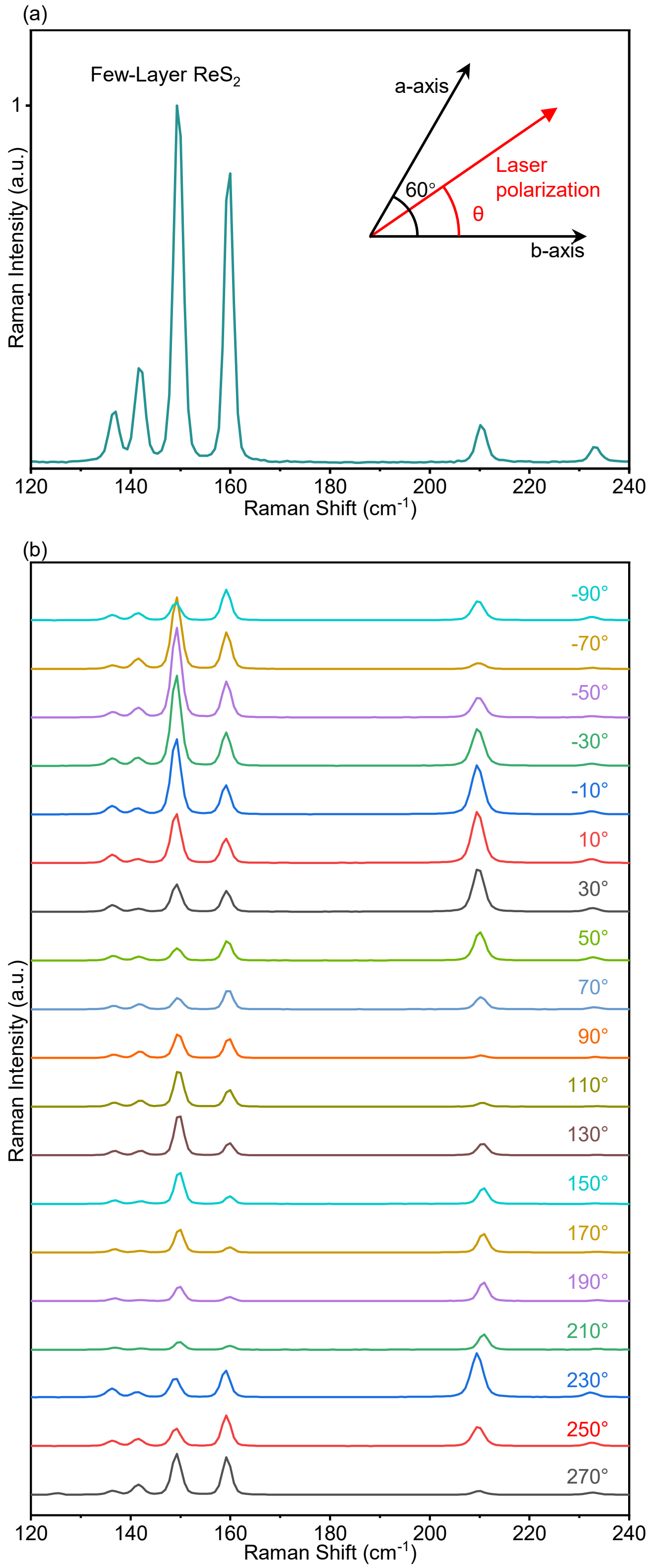

Fig. 2. Anisotropy in ReS_2 resonator. (a) Raman specturm of ReS_2 at 90° polarization, where the b-axis is perpendicular to the laser polarization. The polarization angle is illustrated in the inset. (b) Polarization dependence of ReS_2 Raman spectra. The deviation from perfect repeatablility (when polarization is rotated 180°) is due to the lack of precise control of polarization given limitation in the experimental setup.

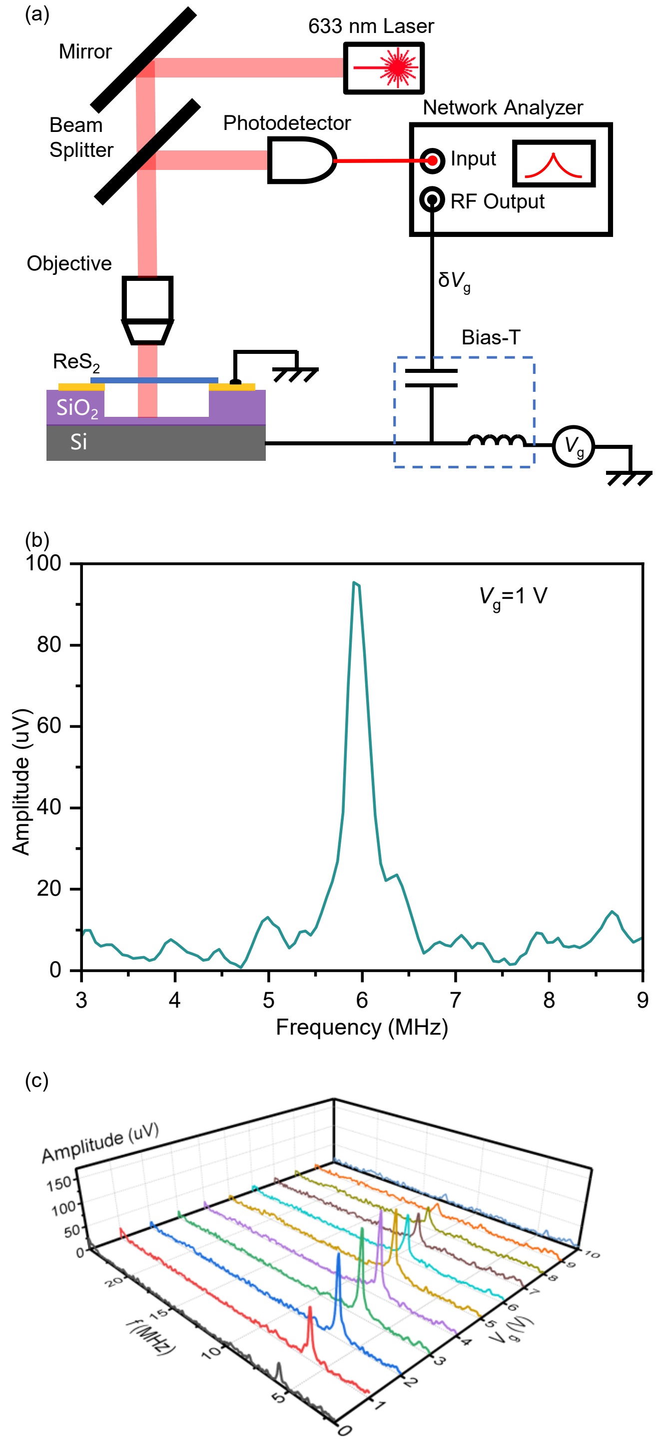

Fig. 3. ReS_2 resonator with optical driving. (a) Measurement setup. (b) Resonant response. (c) Frequency tuning.

III. Conclusions

We demonstrate NEMS resonators based on ReS_2, an anisotropic layered semiconductor. We show that nanomechanical resonances can be efficiently excited and detected using both optical and electrical driving schemes, and the frequency can be effectively tuned with electrostatic gating. Our findings can lead to further exploration and exploitation of these atomically-thin anisotropic 2D semiconductors towards novel NEMS devices.

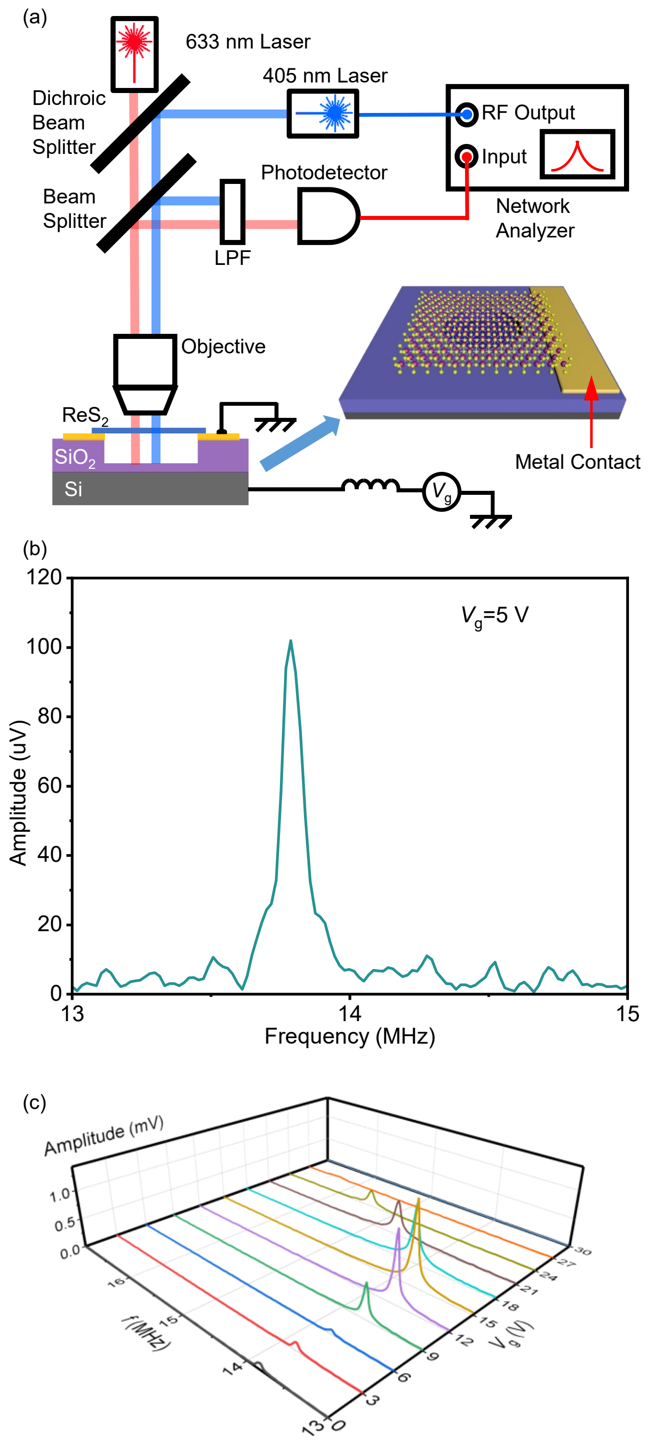

Fig. 4. ReS_2 resonator with electrical driving. (a) Measurement setup. (b) Resonant response. (c) Frequency tuning.

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