A multifunctional micro-electro-opto-mechanical (MEOM) platform based on phase-transition materials

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Abstract: we demonstrate a new MEOM multifunctional platform activated by the structural phase transition of an embedded vanadium dioxide layer. Its diverse stimuli and > 50% optical modulation depth over a broad wavelength range promise versatile applications.
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1. Introduction

Photonic devices with dynamic tunability have drawn tremendous attention in the past several decades. Among various approaches, micro- and nano-electro-opto-mechanical systems (MEOMS and NEOMS) featuring reconfigurability and reliability have shown promising applications when micro mirrors or micro lenses are integrated into MEMS/NEMS. Though several types of such devices have been commercialized, the integrated optics are still macroscopic optics. Miniaturization of these devices remains a challenge. Furthermore, the complexity of those macroscopic structures limits their design flexibilities. Recently, subwavelength structures, such as nanobeams and meta-atoms, have been demonstrated as important components of modern MEOMS/NEOMS, which greatly reduces the device size for integrated applications [1]. However, to the best of our knowledge, all such devices reported to date suffer from either low optical modulation depth (<~10%) [2] or large operation voltage (>10V) [3], insufficient for practical applications and integration with modern CMOS circuit. Ideally, a good MEOMS device should have subwavelength feature sizes, large modulation depth, simple on-chip electrical actuation, and design flexibility.

Here, we demonstrate a new MEOMS design based on a phase-transition material, vanadium dioxide (VO_2), which has a reversible phase transition between an insulating (I) and a metallic (M) phase slightly above room temperature. The phase transition is accompanied by an abrupt lattice expansion (M to I) or contraction (I to M) along the c_R-axis of VO_2 crystals. The I-to-M phase transition is triggered when the temperature increases beyond a critical temperature (T_c = 68 °C) [4]. The phase transition-induced strains in VO_2 are much larger than the strains induced by thermal expansion and typical piezoelectric actuations [5]. Recently, we have demonstrated a design procedure based on multilayer structures that can arbitrarily manipulate the curvatures of VO_2 cantilever actuators at both M and I phases [6]. This enables a new platform for MEOMS and NEOMS devices – multifunctional VO_2 cantilever actuator arrays. We designed and characterized MEOMS devices based on this new platform, which fits the requirements of good MEOMS devices summarized above. Unlike conventional VO_2-based optical devices whose tunable properties are largely dependent on and limited by the optical properties of VO_2 itself, the performance of our MEOMS devices mainly relies on the reconfiguration of metallic structures, while VO_2 is integrated as the mechanical actuation material. As such, large flexibility in materials selection and working wavelengths, as well as versatile functionality, can be achieved.

2. Experiment

The schematics of the first MEOMS device are illustrated in Fig. 1a. All geometric parameters are readily tunable. The structure was fabricated on a Si substrate covered by a 200 nm-thick platinum (Pt) layer. The cantilevers are designed to be curved upwards at room temperature (I phase) and flat at temperatures above T_c (M phase). To achieve that design, we constructed a tri-layer structure containing VO_2, chromium (Cr), and gold (Au) layers with optimized thicknesses. The cantilevers are supported by two rectangular anchors facing each other, which are also large enough to prevent peel-off during the removal of the sacrificial material (SiO_2) by wet etching. The left inset of Fig. 1a shows the SEM image of an as-fabricated MEOMS device at room temperature.

The reconfigurable behavior of the MEOMS device before and after the phase transition of VO_2 can be examined conveniently under an optical microscope. At room temperature, all cantilevers bend up uniformly (left panel of Fig. 1b). The array appears dark due to the deflection of light by the bent cantilevers. When the temperature is increased above T_c, the VO_2 layer drives the cantilevers to bend downwards, eventually attaining a flat state (right panel of Fig. 1b), which is verified by the strong reflection from the device.

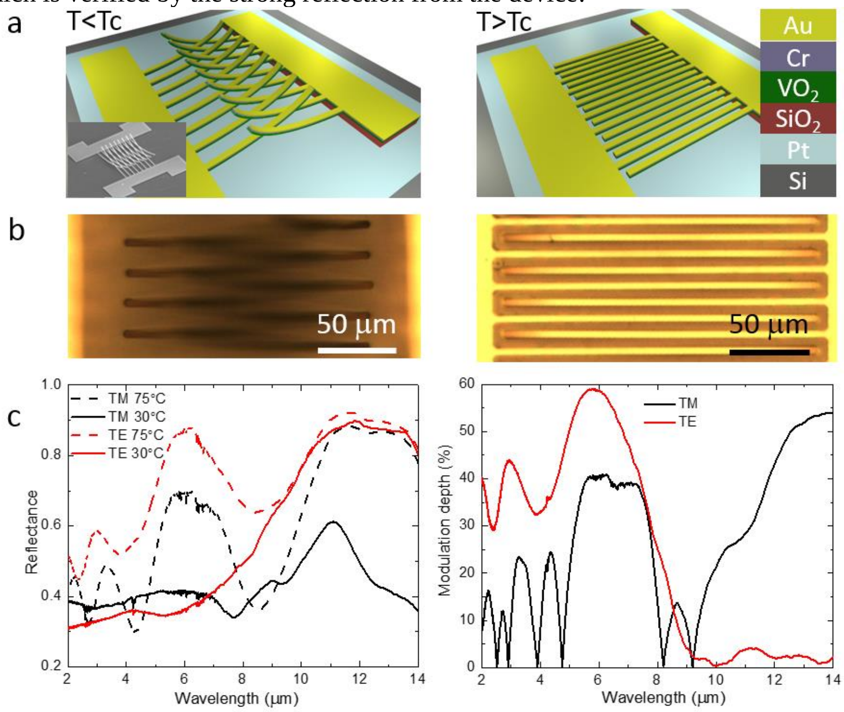

Fig. 1. (a) Schematics of the MEOMS device, showing curved cantilevers at room temperature (left) and flat cantilevers at temperature above Tc (right). The left inset shows a SEM image of an as-fabricated MEOMS device. The right inset shows the sequence of layered structure; (b) top view of a MEOMS device at room temperature (left) and 75 °C (right) under an optical microscope; (c) Reflection spectra (left) and corresponding modulation depths (right) of a MEOMS device.

The reflection spectra of fabricated MEOMS devices were characterized by an FTIR. The normalized reflectance and corresponding modulation depth of one sample are shown in Fig. 1c. The MEOMS device shows dramatic modulation over a wide wavelength range before and after the phase transition of VO_2 for both TM and TE polarized incident light. Such large optical modulation depths of our MEOMS devices already promise various applications, including selective wavelength reflection spectrum filters and diffraction gratings. Other applications, including active enhanced absorbers and reprogrammable electro-optic logic gates, were also experimentally demonstrated.

To minimize heat dissipation and reduce power consumption during electrical control, the cantilevers were also optimized into U-shape structures, which allowed electrical current to flow through the cantilevers directly. Based on experiments, the minimum voltage to operate the MEOMS devices is ~0.5 V, compatible with the state-of-art voltage level (~1 V) of CMOS circuits [7], facilitating the integration of our MEOMS devices into CMOS systems for further applications of "photonics on a chip".

3. Conclusion

We demonstrated a multifunctional MEOMS platform with greater than 50% light modulating capabilities and multiple control methods. This MEOMS platform paves the way for a wide variety of practical MEOMS devices with versatile dynamic functionalities and high performance for future electronic–photonic systems.

4. References

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