Combined molibdenum trioxide/vanadium dioxide multilayers for a new class of tunable photonic devices in the mid-infrared

Daniele Ceneda[a], Martina Mercurio[a], Dominique Persano Adorno[b], Roberto Macaluso[c], Marco Centini[a], Maria Cristina Larciprete*[a]
[a]Department of Basic and Applied Sciences for Engineering, Sapienza University, Via A.Scarpa 14, 00161, Rome, Italy; [b]Department of Physics and Chemistry “E.Segrè”, University of Palermo, Palermo, 90128, Italy; [c]Department of Engineering, University of Palermo, Palermo, 90128, Italy

*mariacristina.larciprete@uniroma1.it

ABSTRACT

In this work, we propose a strategy for developing actively tunable mid-infrared photonic devices by integrating polaritonic and phase-change materials. Specifically, we combine the anisotropic response of molybdenum trioxide (α-MoO_3) with the thermochromic behavior of vanadium dioxide (VO_2) in a large-area multilayer architecture. In order to optimize their interaction, we performed electromagnetic simulations and evaluated deposition conditions, adjusting key film parameters such as thicknesses. Based on these results, we fabricated thin-film stacks using Pulsed Laser Deposition (PLD), enabling precise control over composition and growth of large area α-MoO_3 films. The resulting structures were characterized by Fourier Transform Infrared Spectroscopy (FTIR) as a function of temperature, polarization, and incidence angle. The measurements reveal a clear modulation of α-MoO_3 phonon-polariton resonances triggered by the insulator-to-metal transition of VO_2. This thermally induced tunability of the mid-infrared optical response suggests promising applications in areas such as thermal camouflage and radiative cooling, where dynamic control of thermal emissivity is critical. Overall, our study demonstrates that combining a polaritonic medium with a phase-change layer provides an effective route toward infrared photonic components with real-time reconfigurability.

Keywords: polar materials; van der Waals materials; thermochromism; phase change material; radiative cooling; infrared photonic; pulsed laser deposition; multilayer stack

1. INTRODUCTION

Polar materials, including ultra-thin van der Waals (vdW) materials, have emerged as promising platforms for next generation photonic devices due to their unique structural properties and remarkable optical properties. These two-dimensional (2D) materials exhibit relatively weak interlayer van der Waals bonding, which allows them to be easily exfoliated into few-layer nanosheets. This feature enables the formation of complex heterostructures that can integrate multiple functionalities within a single device. Besides, due to their strong optical anisotropy, they allow strong field localization by the excitation of surface waves called surface phonon polaritons (SPhPs), showing great potential for IR sensing applications up to terahertz (THz) regime [1] and for the realization of compact IR photonic devices [2].

Among vdW materials, molybdenum trioxide (α-MoO_3) is attracting significant attention [3] due to its ability to support surface phonon polaritons (SPhPs) in three distinct mid-infrared bands, corresponding to its three orthogonal crystallographic axes (10–20 μm range). This peculiar behavior results in its biaxial and naturally hyperbolic character [4]. The versatility of α-MoO_3 can be further enhanced by integrating it with functional materials. Recent work has demonstrated that coupling α-MoO_3 crystalline flakes with vanadium dioxide (VO_2) - a phase-change material exhibiting a thermally driven insulator-to-metal transition at ~68 °C - enables active tuning of polariton resonances [5]. However, the realization of compact and scalable α-MoO_3-based platforms for infrared photonics remains technologically challenging. In particular, the fabrication of large-area, oriented, and single-phase α-MoO_3 films is still an open issue.

2. METHODS

In this work we propose MoO_3/VO_2 multilayer structures in which the thermochromic layer of VO_2 enables active shifting and switching of phonon resonances at the MoO_3/VO_2 interface, through temperature induced phase transition in VO_2. While thermal control of the spectral and polarization response of α-MoO_3 has been previously demonstrated using micrometric flakes [Sina], our approach focuses on large area multilayer structures that can be fabricated via a single, scalable deposition process, pushing the capabilities beyond the current state of the art. In particular, Pulsed Laser Deposition (PLD) has proven to be a versatile and cost-effective technique for growing oriented α-MoO_3 films over large areas at temperature ranging between 400 and 500 °C [6] (see Figure 1a), achieving strong out-of-plane anisotropy and preferential z-axis orientation. To enhance the dynamic tunability of phonon-polaritonic resonances, we integrate a VO_2 layer beneath the MoO_3 film (see Figure 1b). VO_2 undergoes an abrupt, thermally driven insulator-to-metal phase transition at ~68 °C, switching from a monoclinic insulating phase to a tetragonal rutile metallic phase, with a corresponding drastic change in optical properties. This transition can significantly affect the dielectric environment at the interface, resulting in a tuning of the MoO_3 phonon resonances.

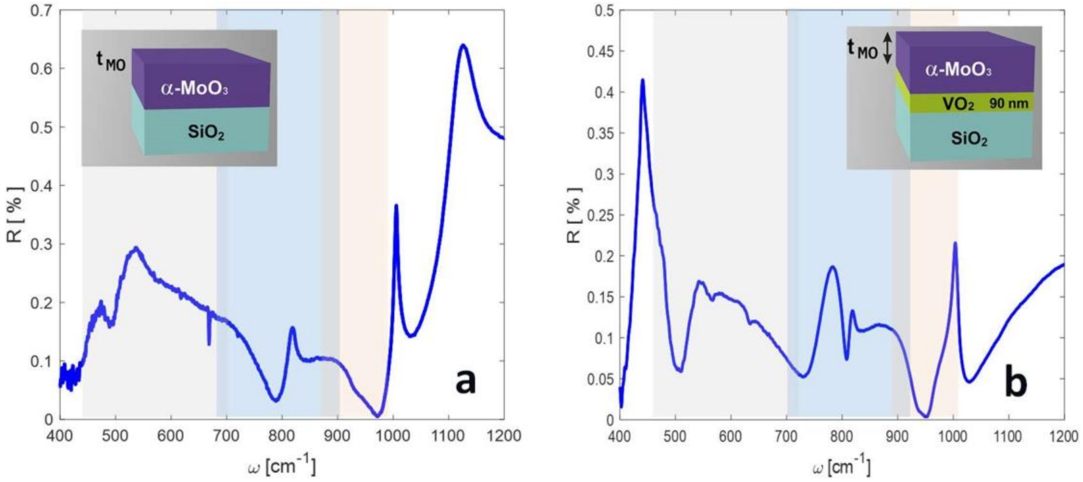

Figure 1. Reflectance FTIR spectra measured at 15° incidence angle for (a) single MoO_3 film and (b) the MoO_3/VO_2 stack. As a reference we added the edges of the Reststrahlen bands of bulk α-MoO_3 along x-(blue), y-(red) and z-(green) directions. In the insets: schematic illustration of samples under study.

3. CONCLUSIONS

This study highlights the potential of MoO_3/VO_2 multilayers as a platform for actively tunable mid-infrared photonic devices. By leveraging the thermally induced phase transition of VO_2, our design enables dynamic modulation of phonon-polariton resonances in large-area, scalable architectures. This approach represents a significant step toward the development of reconfigurable infrared optical components, with promising applications in thermal management, sensing, and adaptive photonic systems.

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