2.5D-MoS_2-Based Non-Volatile Optical Memory for Integrated Photonics

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Abstract: We proposed an integrated non-volatile optical memory cell using novel analog linear photo-response resistance switch based on 2.5D MoS_2. It enables a thermally stable and scalable solution for integrated optical memory components. © 2022 The Author(s)

1. Introduction

Integrated photonics is playing increasingly a key role in optical computing, optical communication, and optical sensing. Despite its tremendous versatility, the lack of suitable integrated optical memory has posed significant limitations for its further development. Over past the decade, extensive researches have been carried out based on different optical memory, including Vertical-Cavity Surface-Emitting-Laser (VCSEL) -based optical memory [1], Phase-Change-Material (PCM)-based optical memory [2] and 2D-material-based Carrier Trapped Optical Memory (CTOM) [3]. However, these memory candidates have some shortcomings, in terms of scalability, thermal stability and process integration complexity [4]. To address these issues, we propose a novel integrated 2.5D-MoS_2-based metal-semiconductor-metal (MSM) structure to function as a non-volatile optical memory. Here, 2.5D material is an intermediate polymorphic state between 2D material and bulk crystal, enabling large-scale integration. The optical memory utilizes abrupt resistance switching properties to store optical information in the resistance that can be read out electronically. Remarkably, the write voltage (V_{WRITE}) has a high linear correlation with the input light power (P).

2. Device Fabrication

2.5D MoS_2 ink is prepared by exfoliation of 3D MoS_2 crystal for 1 hour, followed by formulation of ink through mild sonication (30 minutes), centrifugation (1000 r.p.m. for 3 minutes) and washing in Isopropyl Alcohol (IPA). Afterwards, this ink is directly spin-coated on the substrate to form the continuous 2.5D MoS_2 film. Fig. 1(a) shows the topography of patterned 2.5D MoS_2 film characterized by Atomic Force Microscopy (AFM). The AFM reveals that MoS_2 film generated by stacked MoS_2 nanosheets has a low surface roughness of 1.2 nm, which indicates good uniformity that is critical for reliable operation of the optical memory. Fig. 1(b) shows the device schematic design in a simple MSM configuration. A bottom Au bottom electrode is formed through electron beam lithography, metal evaporation and lift-off process. Subsequently, the 2.5D MoS_2 thin film is patterned by electron beam lithography, followed by etching with reactive O_2 plasma using reactive ion etching (RIE). Finally, the ITO electrode is deposited on the top of 2.5D MoS_2 and etched by Cl_2 plasma using RIE to obtain the final device (Fig. 1c). The energy dispersive X-ray image taken at the device region shows uniform distribution of the contact and switching layer. Furthermore, an 8×8 crossbar array of the optical memory switches has been fabricated, demonstrating the feasibility of the proposed approach for large-scale optical memory implementation.

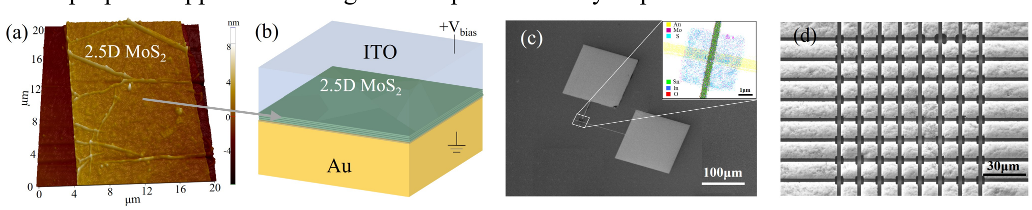

Fig. 1. (a) Surface topography image of patterned 2.5D MoS_2 layer. (b) Design of non-volatile optical memory cell based on 2.5D MoS_2. (c) SEM image of optical memory cell. (d) SEM image of optical memory crossbar array.

3. Measurement Results

Fig. 2(a) shows the current-voltage (I-V) characteristics of the 2.5D MoS_2 optical memory cell under the illumination with different light power. 520 nm wavelength of light source has been chosen as determined by the bandgap of MoS_2 (1.29 eV~1.88 eV). The resistance of the optical memory cell switches from high resistance state (HRS) to low resistance state (LRS) when the applied voltage bias (V_{bias}) reaches V_{WRITE}. Significantly, V_{WRITE} has a linear relationship with the input light power as shown in Fig.2 (b). The variable range of V_{WRITE} under different illumination condition is defined as optical memory window in this work. As shown in Fig. 2(a), a considerable memory window of 1.9 V has been reached ranging from 0.8 V to 2.7 V. This feature enables conversion of optical information to electronically readable memory states. Fig. 2(c) demonstrates the non-volatile feature of the device, which is cable of remaining unchanged during 600 minutes in HRS or LRS. In addition, as shown in Fig. 2(d) with P=141.1 pW·μm^{-2}, such device enables temperature-insensitive WRITE switching characteristics, highlighting its thermal stability, which originates from the intactness of the device structure as well as the chemical stability of MoS_2 switching layer. Fig. 2(e) shows the application of the optical memory crossbar array in static mode and dynamic mode, respectively. In static mode, constant voltage has been applied to each optical memory cell. Generally, the optical memory cell is written when the input light power exceeds the light power threshold corresponding to the applied voltage as shown in Fig 2(b). This performs a digital memory function. On the other hand, in the dynamic mode, a cycling sweeping voltage has been applied to each optical memory cell, and specific light power induces resistance switching at corresponding V_{WRITE}. In this case, all the optical information can be stored as a series of V_{WRITE}. Fig. 2(f) benchmarks the essential performance metrics of two mainstreamed optical memory cells (PCM and CTOM) with our work. We have shown remarkable superiority in scalability, thermal stability, analog operation, integration simplicity, energy efficiency and versatility.

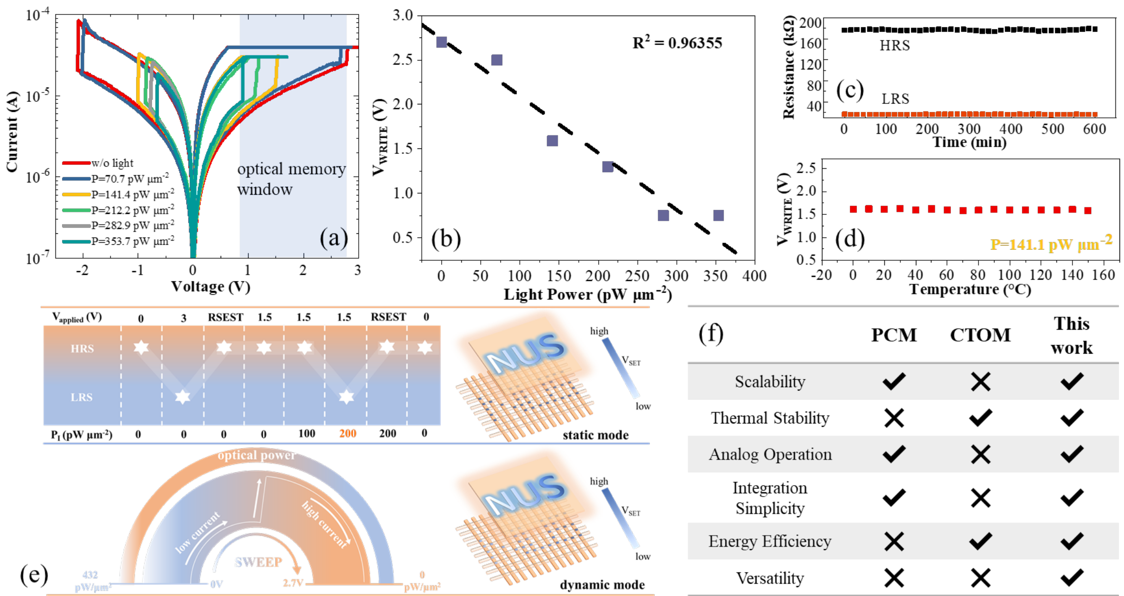

Fig. 2. (a) I-V curves of optical memory based on 2.5D MoS_2 measured under different input light power at 520 nm. (b) The values of V_{WRITE} at different input light power. (c) Retention measurement of the optical memory. (d) V_{WRITE} variation with different environment temperature. (e) Static and dynamic modes of optical memory crossbar array. (f) Benchmark table of state-of-art optical memory cells.

4. Conclusion

We have demonstrated a non-volatile optical memory based on novel 2.5D MoS_2 material. The linear relationship between V_{WRITE} and the input light power enables the storage of optical information in static or dynamic modes. Our approach would be a promising candidate for optical information storage in integrated photonics, which could promote the advance of future machine learning and information processing.

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