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Improved microwave absorbing properties by designing heterogeneous interfaces in Mo@2D-MoS_2

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ABSTRACT

Microwave absorbing materials are usually designed to solve electromagnetic impedance matching by compositing the magnetic and dielectric loss materials. Herein we demonstrated that the Mo@2D-MoS_2 nanocomposites synthesized by arc-discharge method exhibit excellent microwave absorbility at gigahertz. Based on the transmission line theory, we prove quantitatively that more than 90% of the electromagnetic power can be attenuated at 5.6–18 GHz. The experimental results and theoretical analyses evidence that the heterogeneous interfaces and the few layers of the two-dimension graphene-like structures of Molybdenum disulfide (MoS_2) contribute to the enhancement of the microwave absorption properties. The present study has important implications in understanding the microwave absorbing properties of the 2D materials and provides a new strategy for the design of variety microwave absorbers.

1. Introduction

Because of the wide applications in the wireless communications and high-frequency devices, electromagnetic pollution has appealed to public concerns. An ideal electromagnetic wave absorbing material should be lightweight and exhibit high absorption efficiency in a broad frequency band at a low filler loading ratio [1]. Among many electromagnetic wave absorbing materials, nanomaterials have a great potential for resolving these requirements, attracted by their unique characteristics of low density, distinct size effect, and nanostructure [2,3]. Nano-sized dielectric or magnetic materials, such as graphene [4], α-Fe_2O_3 [5] and Cu [6], have been manufactured to realize the electromagnetic wave absorbility [7]. Furthermore, it is recently proved that complex nanomaterials can greatly enhance the microwave absorbing properties, such as Co@C [8], Fe@ZnO [9], CNT/Fe [10] and Fe_3O_4@Fe [11].

As a representative transition-metal dichalcogenide, 2D-molybdenum disulfide has received an advanced study because of its photoelectric property [12], saturable absorbility [13] and semiconductivity [14]. 2D-MoS_2/Graphene has been applied in the area of electromagnetic wave absorption in broadband [7,15]. More importantly, the synergistic effect raised from their nanoscale core@shell interfaces would contribute to the additional enhancement of the microwave absorbing properties [16,17].

In this study, we synthesized the Mo@2D-MoS_2 nanocomposites by in-situ arc-discharging a compressed anode of molybdenum and molybdenum disulfide powders in Ar and H_2 atmosphere. By compositing the semiconducting shell and the magnetic metal core within each particle, the relatively complex permeability and permittivity can be effectively combined, leading the composites exhibiting an effective electromagnetic wave absorption bandwidth of 4.7 GHz. Owing to its simple synthesis approach and significant electromagnetic characteristics, the Mo@2D-MoS_2 nanocomposites could to be helpful to enhance the microwave absorbing property.

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2. Experimental section

2.1. Synthesis of Mo@2D-MoS_2 nanocomposites

Mo@2D-MoS_2 nanocomposites synthesized by a modified arc-discharge method, which has been described elsewhere [18,19]. The microsized molybdenum and molybdenum disulfide powders were homogeneously mixed with the weight ratio of 4: 1, and then compressed into a bulk as the anode. During the arc-discharging process, the tungsten rod fixed on the opposite side served as the cathode. Before staring the arc, the chamber was evacuated to 5×10^{-3} Pa, and then inlet with argon (Ar, 0.1×10^5 Pa) and hydrogen (H_2, 0.2×10^5 Pa). The anode was evaporated by simultaneously arc-discharging at 25–30 V and 200–300 A for 10 min, which can produce ~0.1 g powders, in while the current and voltage were adjusted by the distance between the two electrodes. After a passivation process for ~6 h, the as-made powders were collected for usage.

2.2. Characterizations

X-ray diffraction (XRD, PANalyical X'Pert Pro diffractometer) with a CuKα ($\lambda = 0.15405$ nm) irradiation was carried out to identify the phase composition, with a voltage of 30 kV, a current of 30 mA and a scan step of 0.2°. The nanostructure was characterized by transmission electron microscope (JEOL-2100F) at an accelerated voltage of 200 kV. X-ray photoelectron spectroscopy (XPS, Thermal Scientific K Alpha) was performed with a Phoibos 100 spectrometer. For electromagnetic parameter measurements, the sample was prepared by uniformly mixing the Mo-MoS_2 nanocomposites with 50 wt% wax paraffin, and then casting into a toroidal shaped sample with an outer diameter of 7.00 mm, inner diameter of 3.00 mm, and thickness of 3.50 mm. The frequency band was recorded at 2–18 GHz using Keysight N5222A vector network analyzer (VNA) with a sweep oscillator and *S*-parameter test setup.

3. Results and discussion

The XRD results of the as-prepared Mo and Mo@2D-MoS_2 nanocomposites have been shown in Fig. 1a. The result of Mo reported in PDF#89-5156 is also presented for comparison. The TEM and high-resolution TEM (HR-TEM) images shown in Fig. 1b, c and d present typical morphologies for Mo@2D-MoS_2 nanocomposites, which evidencing the distinct heterogeneous core/shell structures with the core diameters of ~10 nm. From the high-resolution TEM image in Fig. 1c, it is clearly confirmed that the Mo@2D-MoS_2 nanocomposites have a similar microstructures as the Fe@C nanocapsules that we previously reported [20]. The 2D-MoS_2 shell with a lattice distance of ~6.4 Å corresponding to (002) planes contains obvious ripples and defects, which are most likely resulted from the non-equilibrium cooling process [21]. It is clearly proved that the core@shell nanostructure is comprised of a Mo core and a 2D-MoS_2 shell, as shown in the inset illustration in Fig. 1c. In the HR-image in Fig. 1d, the spacing lattice fringes are approximately 0.223 nm corresponding to the (110) planes of molybdenum, the fast Fourier transform pattern of which is presented in the insets in Fig. 1d [22].

XPS spectra has been carried out to evaluate the surface

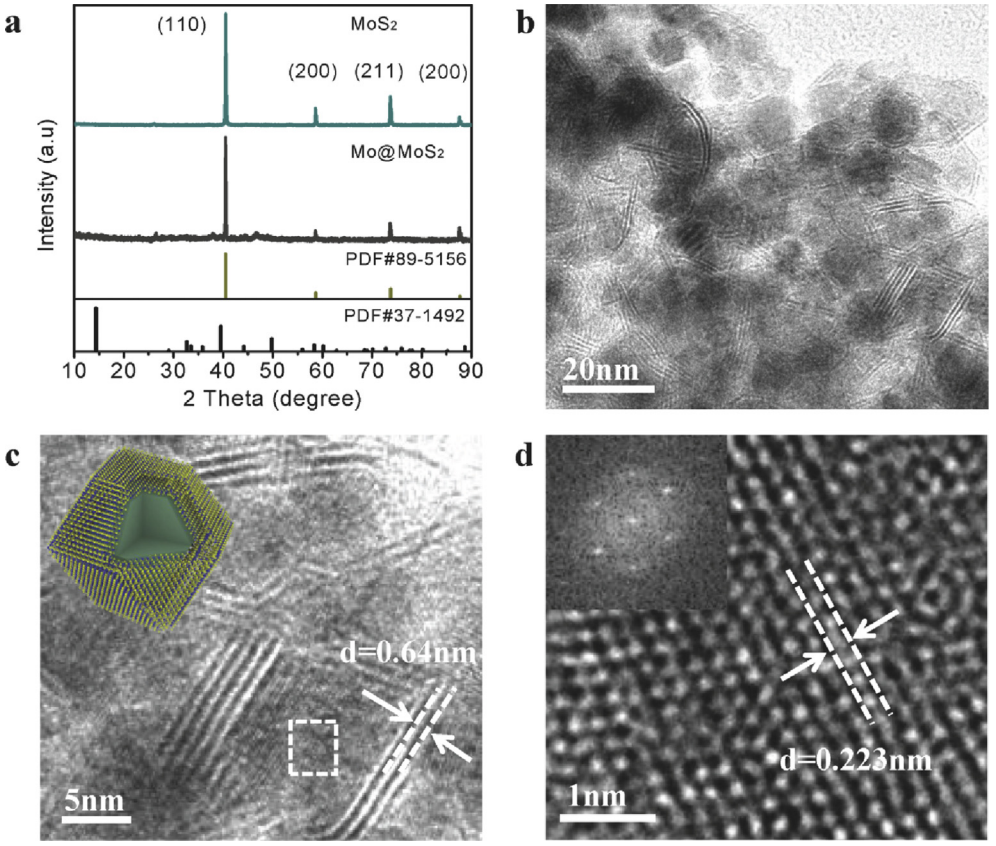

Fig. 1. Microstructure characterizations of Mo@2D-MoS_2 nanocomposites. (a) XRD pattern of Mo@2D-MoS_2 nanocomposites powders; **(b)** and **(c)** TEM and HR-TEM images of Mo@2D-MoS_2 nanocomposites, showing a Mo core with the diameter of 10 nm and few 2D-MoS_2 with the thickness of 0.65–1.95 nm; **(d)** the HR-TEM images and the fast Fourier transform pattern of Mo in Mo@2D-MoS_2 nanocomposites.