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Ultrahigh molecular weight polyethylene composites with segregated nickel conductive network for highly efficient electromagnetic interference shielding

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ABSTRACT

Conductive ultrahigh-molecular-weight polyethylene (UHMWPE) composite with segregated nickel (Ni) structure which exhibited highly efficient electromagnetic interference (EMI) shielding performance was fabricated in this work. By synthesizing nickel coated UHMWPE particles via electroless deposition and then hot compressing, the prearranged thin Ni layer could only selectively locate at the boundary between UHMWPE regions due to the specific high melting viscosity of UHMWPE, and thus constructed a well connected segregate Ni conductive network in UHMWPE matrix. Owing to the advantage of segregated network structure, the UHMWPE/Ni composite shows a low percolation threshold and high conductivity, and exhibits an EMI shielding effectiveness (SE) of average 55 dB with Ni content of only 2.58 vol% in X-band. This result indicates the segregated UHMWPE/Ni composite can serve as an ultra-efficient material for EMI shielding applications.

1. Introduction

With the widespread practical applications of modern electronic instrument and telecommunication technologies, electromagnetic interference (EMI) has become a serious problem in modern society. Developing high-performance EMI shielding materials can be essential to address these problems in both civil and military applications [1–3]. Conductive polymer composites (CPCs), in place of conventional high-density and corrodible metal EMI shielding materials, may be the best candidates to satisfy the current EMI shielding needs due to their light weight, easy processing ability, and tunable performance [4,5].

Over the past decades, CPCs with various conductive fillers have received extensive attention in EMI shielding area [6,7]. Metal fillers, such as silver or nickel, are the potential additives for high EMI shielding CPCs because of their ultra-high intrinsic conductivity, nevertheless, high filler loadings (>50%) are always required to form efficient conductive networks, which inevitably result in high density, high cost and low processability [8]. Construction of segregated structure is a promising approach to form the efficient conductive networks at very low filler content and possess a reasonable EMI shielding effectiveness (EMI SE) [2,4,9]. However, the fabrication of segregated metal/polymer CPCs with ideal metal conductive network remains a challenge owing to the poor dispersion, low connectivity and geometric disadvantages of metal fillers [10].

In this work, we fabricated an ultrahigh-molecular-weight polyethylene (UHMWPE) composite with segregated 3D nickel (Ni) conductive network *via* a facile electroless deposition and compression molding strategy. The thin layer of Ni was prearranged on the surface of UHMWPE granules by electroless deposition, and then constructed a well connected 3D conductive network with segregated structure among the boundaries between UHMWPE domains during the hot compression. Such a segregated structure gives rise to a very high EMI SE of 55 dB in X band for UHMWPE/Ni composite with Ni content of only 2.58 vol%, which is the highest value among the reported metal/polymer shielding composites at similar filler content.

2. Experimental

UHMWPE granules were supplied by Beijing No. 2 Auxiliary Agent Factory, with average diameter of 150 μm, density of 0.94 g/cm^3, and melting temperature of 137 °C. The fabrication of UHMWPE/Ni composites are schematically presented in Fig. 1.

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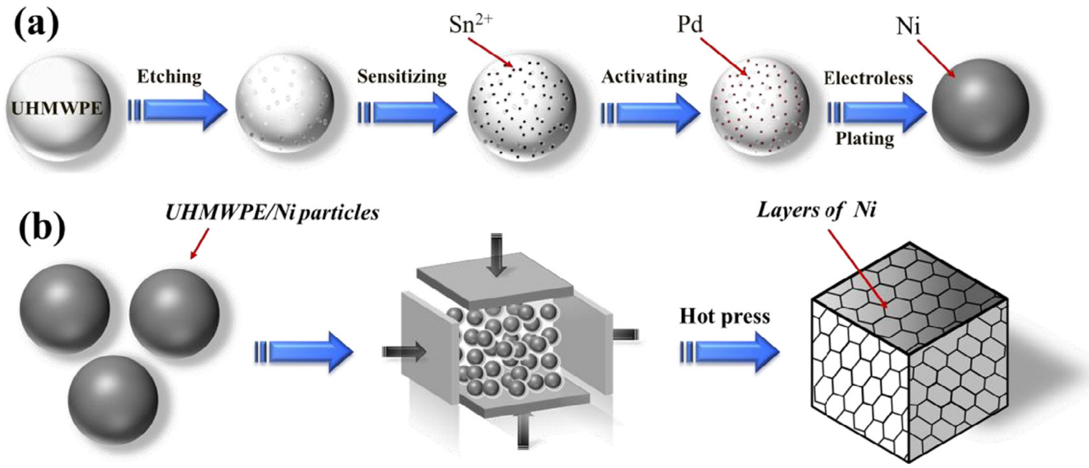

Fig. 1. Schematic illustration for (a) the preparation of UHMWPE/Ni particles and (b) the fabrication of UHMWPE/Ni composites.

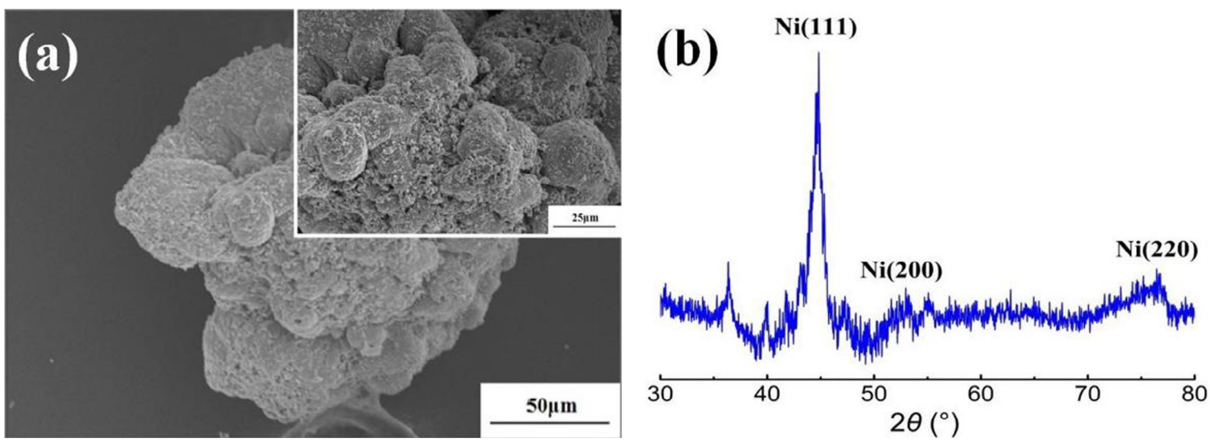

Fig. 2. (a) SEM images and (b) XRD pattern of UHMWPE/Ni particles with 2.58 vol% Ni content.

The preparation of UHMWPE/Ni particles *via* electroless deposition are similar to our previous work [11]: a certain amount of UHMWPE granules were pretreated by etching, sensitizing and activating, and then dispersed in an typical electroless nickel deposition bath that consisted of 2 g of $NiCl_2{\cdot}6H_2O$, 3 g of $C_6H_5Na_3O_7{\cdot}2H_2O$ and 12 mL of $NH_3{\cdot}H_2O$ in 90 mL of deionized water. 4 g $NaH_2PO_2{\cdot}H_2O$ in 10 mL of deionized water as reduction agent was dropwise added into the bath with vigorously mechanical stirring at 60 °C, and the UHMWPE granules gradually submerged in the solution along with the electroless deposition proceeding. After 30 min reaction, the product was filtered, rinsed with distilled water and dried, and then the UHMWPE/Ni particles were obtained. The resultant UHMWPE/Ni particles with different Ni content (0, 0.64, 0.89, 1.02, 1.17, 1.68, 2.56 vol%) were compression-molded into $10 \times 10 \times 2\ mm^3$ boards at 200 °C for 15 min with a pressure of 15 MPa, and then cooled to room temperature by cold compression molding for 5 min to obtain the UHMWPE/Ni composites.

The specimens of UHMWPE/Ni composites were cut into films with 20 μm thickness using a Leica EM UC-7 ultramicrotome for optical observations, and were cryofractured in liquid nitrogen for scanning electron microscopy (SEM) observations. For the electrical conductivity measurement, the volume electrical conductivities of composites higher than 10^{-6} S/m were measured using a SB120 four-point-probe instrument, while lower than 10^{-6} S/m were measured using a ZC36 high-resistance meter. The samples were sliced into circular plates with 12 mm × 2 mm for EMI SE measurements which using a coaxial test cell (APC-7 connector) in conjunction with an Agilent N5232A vector network analyzer according to ASTM ES7-83.

3. Result and discussion

Fig. 2(a) shows the SEM images of the synthesized UHMWPE/Ni particles. It is obvious that a thin nickel layer has been successfully deposited on the surface of UHMWPE after electroless deposition. The layer shows a uniform and compact appearance at high magnification image, which indicates a good connection of Ni in UHMWPE/Ni particles. The XRD pattern of UHMWPE/Ni particles in Fig. 2(b) shows the evident diffraction peaks at $2\theta = 44.54°$, 51.89° and 76.37 °Corresponding to the (1 1 1), (2 0 0) and (2 2 0) crystalline plane of Ni, further indicating the successful deposition of crystallized nickel [12]. All these results give clear evidence that a well-connected nickel layer has been successfully prearranged on the surface of UHMWPE granule.

The segregated nickel network of UHMWPE/Ni composite is presented in Fig. 3. Fig. 3(a) shows the SEM micrograph of the fractured surface of the UHMWPE/Ni composites with 2.58 vol% Ni. The UHMWPE domain exhibits a polyhedral structure and the adjacent individual polyhedron domains form very thin interfaces that consist of prearranged Ni, building the specific 3D frame of the