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Tuning the surface charges of MoO_3 by adsorption of polyethylenimine to realize the electrophoretic deposition of high-exothermic Al/MoO_3 nanoenergetic films

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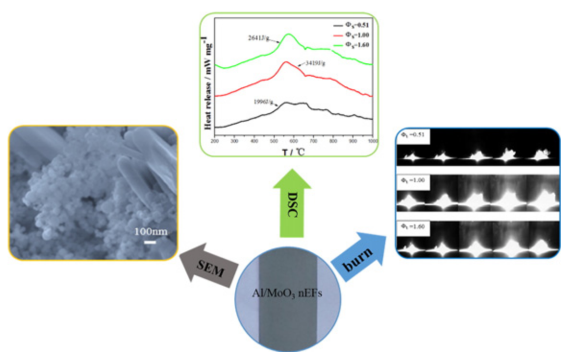
HIGHLIGHTS

- Al/MoO_3 nanoenergetic films were successfully prepared by electrophoretic deposition.
- The surface charge polarity of Al/MoO_3 in isopropyl alcohol was changed by adding appropriate polyethylenimine.
- The maximum heat release was up to 3419 J/g by effectively adjusting kinetics of EPD process.

GRAPHICAL ABSTRACT



The smooth and homogeneous Al/MoO_3 nEFs were successfully prepared by electrophoretic deposition method and exhibited high heat release and best combustion performance.

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ABSTRACT

Al/MoO_3 nanoenergetic films (nEFs) were successfully prepared by the electrophoretic deposition (EPD) method. Polyethylenimine (PEI) was used to modify the surface charge of Al and MoO_3 particles for the first time. In particular, the zeta potentials of Al/MoO_3 were varied from negative value to highly positive one, which could contribute to the co-deposition of Al and MoO_3 particles on the cathode. In addition, an effective adsorption of PEI on the particles was demonstrated by the FT-IR result. The kinetics of EPD process were investigated in this paper that the linear relationship of the equivalence ratio in the deposited film (Φ_d) to that in suspension (Φ_s) was observed for Al/MoO_3 nEFs. Furthermore, The FESEM, EDS and XRD analysis showed that Al/MoO_3 nEFs were homogeneous mixed and composed of Al and MoO_3. The DSC and combustion processes results indicated that the exothermic behaviors were affected by the molar ratio of the fuel (Al) to the oxidizer (MoO_3) in Al/MoO_3 nEFs, and reached to the maximum of 3419 J/g and the most violent combustion as the Φ_s was 1.6, respectively. Al/MoO_3 nEFs with excellent performance could lead to advances in the microelectro mechanical system technologies.

1. Introduction

In recent years, there has been a growing interest in nanocomposite thermites for electrothermal bridge in microelectro mechanical system

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(MEMS) technologies, which normally include metal fuels (Al, Mg) and oxides (e.g. Fe_2O_3, CuO, MoO_3 and WO_3). When the size of thermite particle is reduced to nanoscale, its combustion wave velocity accelerate accordingly [1–5]. A great deal of efforts have been devoted to the fabrication of different kinds of thermites such as Al/CuO, Al/Fe_2O_3, Al/NiO and Al/MoO_3. [6–12]. Among these thermites, the reaction heat of theoretical stoichiometric Al/MoO_3 thermite reaction is up to 4703 J/g which is larger than that of the others [13]. Furthermore, the ignitability of Al/MoO_3 is excellent. Granier et al. have studied that the ignition delay time of nanoscale mixture of Al/MoO_3 was reduced from 1384 ms to around 20 ms, which was favorable for weaponry systems [3].

Owing to unique advantages of Al/MoO_3, its efforts have been reported in the preparation of Al/MoO_3 thermites by using various methods such as physical mixing method [14], sol-gel method [15], arrested reactive milling [16] and magnetron sputtering [17]. The electrophoretic deposition (EPD) is a facile and effective method to deposit coatings with wide applications. By EPD method, the thickness of films prepared on the various substrates, including the relevant complex shape materials, can be easily and effectively controlled through effective adjustment of the deposition time and field strength. However, the challenge of EPD process is how to control co-deposition of charged nanoparticles with the different charge. So far, based on EPD method, a few thermites (Al/CuO, Al/Fe_2O_3, Al/NiO) have been successfully prepared [6–8]. However, there are few reports on preparation of Al/MoO_3. It is difficult to obtain Al/MoO_3 nanoenergetic films (nEFs) in normal EPD process because MoO_3 is negatively charged while Al is positively charged.

In this study, the additive-polyethylenimine (PEI) was applied for modification of the surface charge of Al and MoO_3 particles to prepare Al/MoO_3 nEFs. The principles of particle deposition were investigated through the determination of zeta-potential and the deposition kinetics of EPD process of Al/MoO_3 nEFs. Moreover, the exothermic performance of as-formed Al/MoO_3 nEFs was also evaluated in detail.

2. Experimental

2.1. Materials

Nano aluminum (nano-Al, 50 nm, 99.9%, Aladdin Inc., China) and molybdenum oxide (nano-MoO_3, 99.95%, Klamar Inc. China) were used in this study. The solvent for EPD was isopropyl alcohol. Polyethylenimine (PEI) with an average molecular weight of 10,000 (99%, Aladdin Inc., China) was used as the additive.

2.2. Electrophoretic deposition

Stable dispersion for EPD was made using the total solids loading of 1 g/L in isopropyl alcohol. In order to make the surface of both Al and MoO_3 particles positively charged in isopropyl alcohol, the cationic polyelectrolyte of PEI was added. Then, the produced suspension was sonicated for 25 min. Stainless steel and nickel sheets were used as the anode and the cathode, respectively. The deposition area of electrodes was 5.5 cm × 2 cm, and the distance between the electrodes

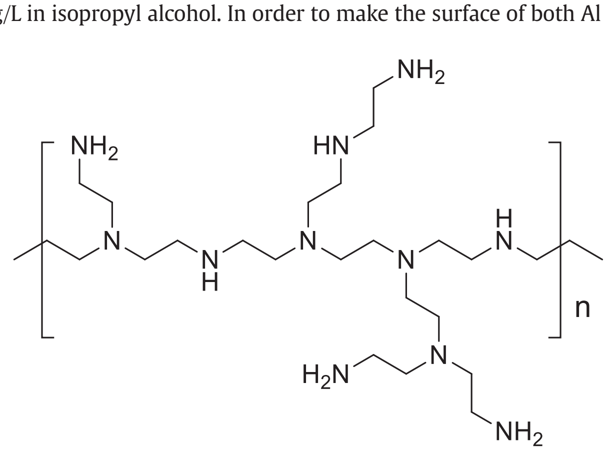

Fig. 1. Chemical structure of PEI.

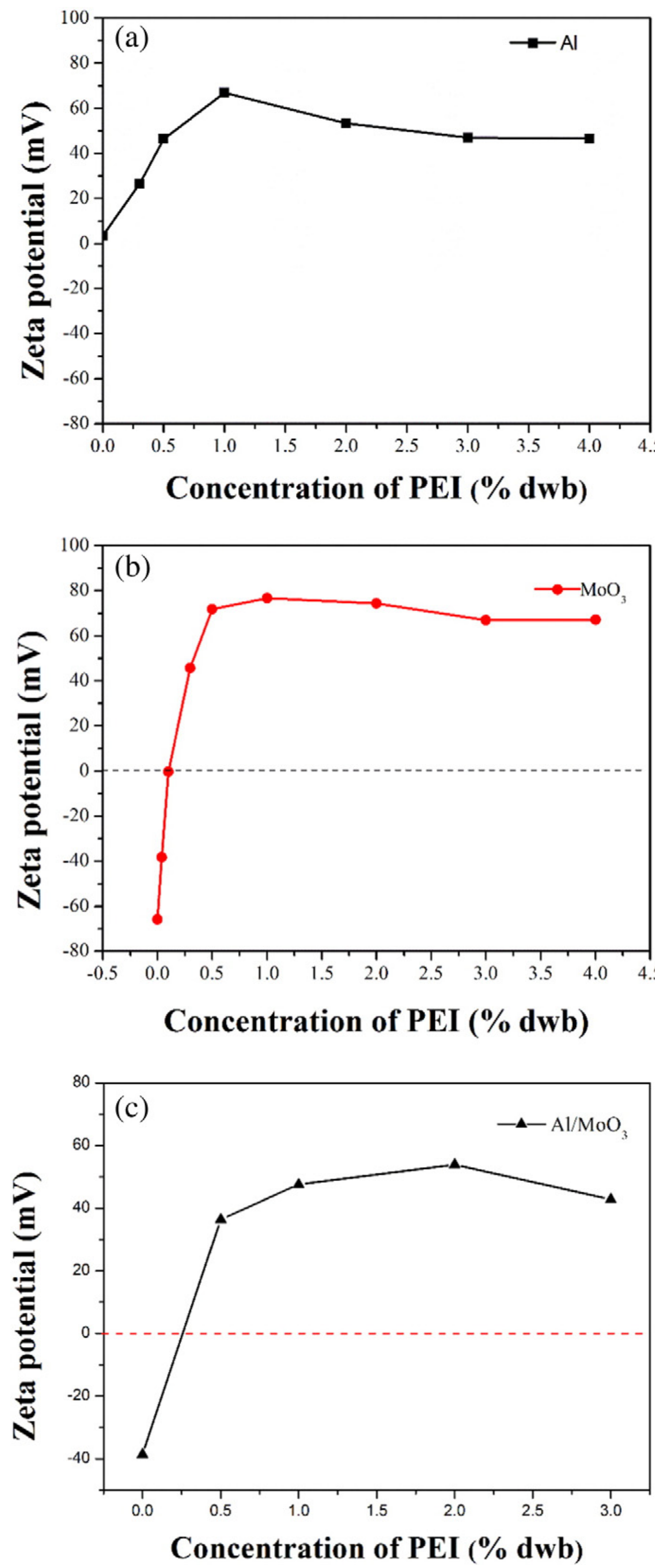

Fig. 2. Effect of PEI concentrations on the zeta potentials of Al, MoO_3 and Al/MoO_3 particles.