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Elimination of droplet rebound off soluble substrate in metal droplet deposition

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ABSTRACT

This letter presents a method and its mechanism of using Ag coating to inhibit rebound of Al droplets over soluble substrates. Experiments show that Ag coating can eliminate droplet rebound, which makes it possible to print complex parts with high-quality inner surface. Further investigation reveals that Ag coating suppresses the rebound of Al droplets through strong chemical interaction between liquid Al and Ag layer, which results in fast Ag dissolution in liquid Al and formation of a dendritic network of Al-Ag intermetallic compounds (IMCs) on their interface. XRD and EDS observation indicates that the IMCs caused by Ag atom diffusion and precipitation are mainly composed of Ag_2Al intermetallics and α-Al solid solutions. It is found that the thickness of the IMCs layer increases as the substrate temperature is raised. The temperature increase of the substrate will slow down the droplet cooling process, which allows more thorough chemical reaction.

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1. Introduction

Droplet-based 3D printing is of great interesting in industrial manufacture [1], and is very promising for fabrication of complex thin-wall microwave devices such as waveguide tubes since it can print a shell by utilizing only several layers of droplets [2]. Because metal droplets are naturally of scalloped shapes [3], the convention droplet-based 3D printing method cannot produce thin-wall tubes with high-quality inner surface that can meet the requirement of electromagnetic transmission [4].

Inspired by the conventional casting process, the cavity surface quality of the printed parts could be improved if soluble cores are used as support materials. However, due to the poor wettability between the metal droplets and the soluble cores (e.g., gypsum and ceramic), the metal droplets rebound from the soluble core surface after impact. Hence, deposition of metal droplets onto such soluble cores remains a challenge.

It is known that metal materials are usually with good wettability with metals, therefore, metal interlayers could be applied to improve the wettability between the molten droplets and substrate [5]. This letter presents a method of coating Ag, which is widely used as the inner surface coating materials in microwave devices, on the soluble cores to prevent Al droplets from rebounding. Moreover, the mechanism of this method to suppress the rebound of Al droplets is investigated.

2. Experimental procedure

Fig. 1(a) shows the schematic of experimental apparatus. Details of the experimental setup have been described in our previous work [6]. Pure Al (99.999%) was heated to 1023 K in a graphite crucible. Uniform droplets with a diameter of ~800 μm were deposited on an Ag-coated soluble gypsum. The Ag coating was fabricated by the combination of silver slurry and screen-printing processes. The surface of the coating was smooth without blistering, cracking or detachment, and its thickness was ~50 μm. The microstructural morphologies and crystalline structure of the samples were examined by scanning electron microscope (SEM, VEGA3, TESCAN) with energy dispersive spectrometer (EDS) and X-ray diffraction (XRD, X'Pert PRO MPD, PANalytical), respectively. The dynamic images of metal droplet impact on solid surfaces were captured by high-speed CCD camera (MotionbBLITZ Cube 1).

3. Results and discussion

Fig. 1(b) and (c) show the initial dynamic behavior of a typical Al droplet impact on soluble gypsum and Ag-coated soluble

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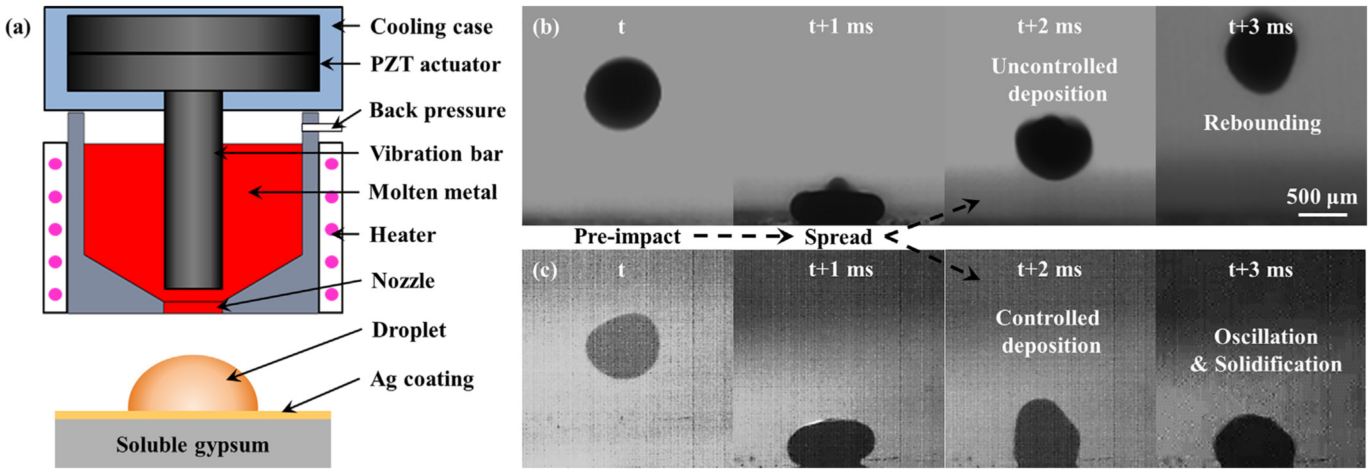

Fig. 1. (a) Schematic diagram of metal droplet generation and deposition; initial dynamic behavior of Al droplet impact on (b) soluble gypsum and (c) Ag-coated soluble gypsum.

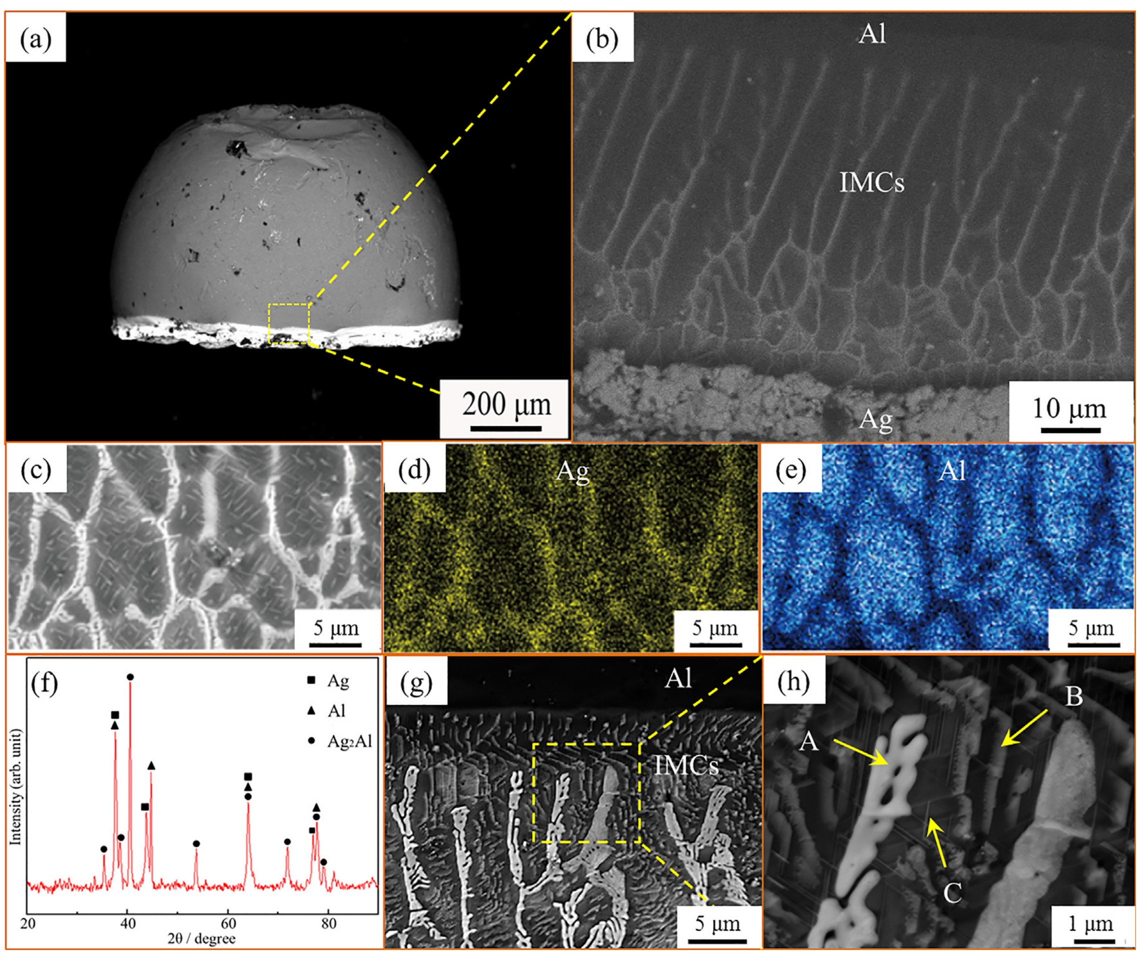

Fig. 2. (a) SEM image of a typically deposited droplet after removing the core; backscattered electron scanning micrograph of (b) the Al-Ag interface and (c) enlarged view of IMCs; elemental mapping of (d) Ag and (e) Al; (f) XRD of the cross-section of droplet-coating; (g) the microstructures of different precipitated phase within IMCs; (h) enlarged view of the selected section in (g).

gypsum, respectively. The temperature of the substrate is 300 K. It indicates that Al droplet rebounds after impacts on the soluble gypsum at time (t + 2) ms. When a droplet deposits on the Ag-coated soluble gypsum, recoil and oscillation occur instead of rebounding from time (t + 2) to (t + 3) ms.

To understand the above observed phenomena, the interface behavior between Al droplet and Ag coating was studied. Fig. 2 (a) shows the side-view of a typically deposited Al droplet after removing the core. The brighter layer (~50 μm) at the bottom of the droplet shows that the Ag coating is tightly bonded to the

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