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Drop-on-demand electromagnetic printing of metallic droplets

Zhiwei Luo[a,b,*], Xiang Wang[a,**], Lingyun Wang[b], Daoheng Sun[b], Zhihong Li[a]

[a] School of Mechanical and Automotive Engineering, Xiamen University of Technology, Xiamen 361024, China
[b] Department of Mechanical and Electrical Engineering, Xiamen University, Xiamen 361005, China

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ABSTRACT

A drop-on-demand electromagnetic printing process has been developed to deposit metallic droplets. An external electromagnetic field and an internal pulsed current pass through the metallic liquid are introduced to make the liquid driven by the resulting electromagnetic force. Experimental results show that the printing frequency equals to the power frequency, and can be larger than 150 Hz when the pulsed width is 5 ms. The printed mercury droplets are uniform in diameter with a mean variation of 2.27%. Smaller nozzle, shorter pulse width and lower magnetic field intensity favor tiny droplets. Besides, printing of molten solder at a temperature of 290 °C is achieved. Our results show promise for electromagnetic printing as a potential tool in drop-on-demand printing fabrication of high-melting-point metals.

1. Introduction

Drop-on-demand (DOD) printing of metallic droplets is of great interesting in industrial manufacturing, as the examples including precise distribution of copper [1], aluminum [2], and solder [3] patterns, which has a broad scope in future applications of rapid prototyping [4], packaging [5], MEMS [6], and printed circuit [7]. To form metallic deposits in the inkjet manner, a simple and universal method is to print droplets from molten metal. Typically, it requires a momentary actuation be applied to the melt in a reservoir, makes the liquid metal ejecting through a small hole and forms a drop. One of the most common apparatus is to force out a drop from a piezoelectric actuation. However, printing metals with high-melting-point (typically about 673 K) remains challenges for the print head design since the piezoelectric materials would lose their function above Curie temperature. It usually requires a medium, such as solid rod, with high-temperature resistance in the print head to transfer the displacement from piezoelectric actuator [4], and the whole apparatus is complicated. Another method is to drive the melt with a pneumatic pulse by applying a back-pressure to the reservoir [8], or use a solenoid actuator [9]. These methods may suitable for the high-melting-point metal, but the printing frequency is usually lower than tens of Hertz.

This work focus on developing an alternative technique for DOD printing of metallic droplets. Instead of the piezoelectric and pneumatic actuator, an external electromagnetic field and an internal current are introduced to make the metallic liquid driven by the resulting electromagnetic force. Compared with the traditional printing techniques for metals, our proposed electromagnetic-field-induced printing method is of costless, simply design, and high-speed ejection with more than hundreds Hertz for patterning high-melting-point metals.

2. Experimental details

Fig. 1(a) illustrates the principle of electromagnetic printing. When the metallic liquid carrying an electric current is placed in a magnetic field, each of the moving charges experiences the Lorentz force and together create a force on the liquid. This force, which usually perpendicular to the both electric current and magnetic field, makes the metallic liquid jet out of the nozzle to generate micro droplet. Fig. 1(b) presents the structure diagram of print head. Two electrodes were inserted in the ends of chamber to supply electric field and current. Permanent magnet is placed on both sides of chamber to provide a magnetic field perpendicular to the electric field. Besides, a nozzle is equipped in the chamber to eject liquid jet. The complete electromagnetic printing apparatus consisting of a print head, a collector, a power supply, a controller and a XY motion stage is illustrated in Fig. 1(c). Obviously, the current and the magnetic field play a decisive role on the force inner metallic liquid. In order to obtain enough driving force, a power source (12 V) with maximum current output of 40 A and a magnetic field intensity of 0.4 T crossing the chamber was used. Mercury and molten solder were served as print ink in present study, and square wave was utilized to drive the ejection of droplets. Fig. 1(d) shows the photograph of print head, with the bottom

* Corresponding author at: School of Mechanical and Automotive Engineering, Xiamen University of Technology, Xiamen 361024, China.
** Corresponding author.
E-mail addresses: zwluo@xmut.edu.cn (Z. Luo), wx@xmut.edu.cn (X. Wang).

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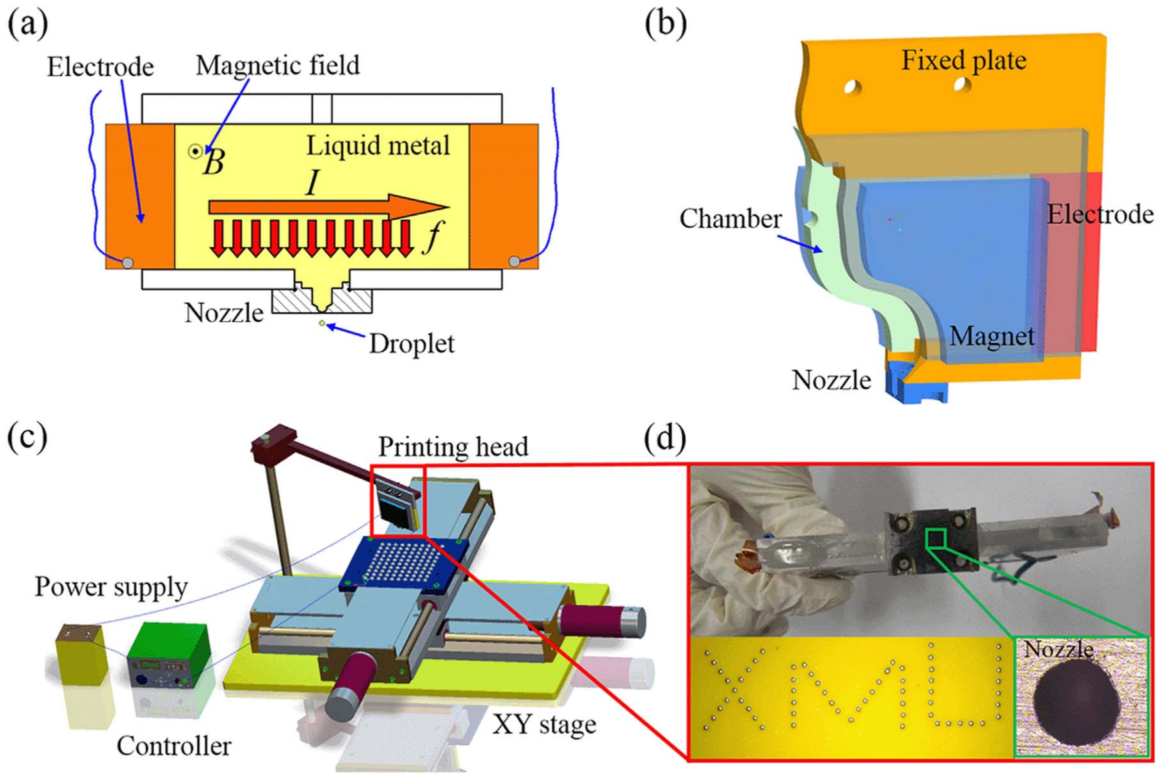

Fig. 1. (a) Schematic of the electromagnetic printing. (b) The structure of print head. (c) Diagrammatic drawing of the electromagnetic printing system. (d) Photography of the print head and the nozzle. The bottom left shows characters "XMU" printed using this setup.

left inset shows an example of mercury pattern "XMU" printed using this experimental platform.

3. Results and discussion

Fig. 2(a) shows the evolution of mercury droplet jetting out of the nozzle under 5 ms pulse width of applied voltage, captured by a high-speed camera (NAC GX-1). When the voltage turned on, the liquid inner chamber suffered an electromagnetic force and started jetting out from the nozzle, as a growing droplet was observed from 0 ms to 5.0 ms. The ejection would stop when the voltage turned off and thus a droplet formed as depicted in 5.8 ms.

Given the fixed pulse width of 5 ms, the printing frequency can be adjusted by changing the duration of OFF period. With the applied

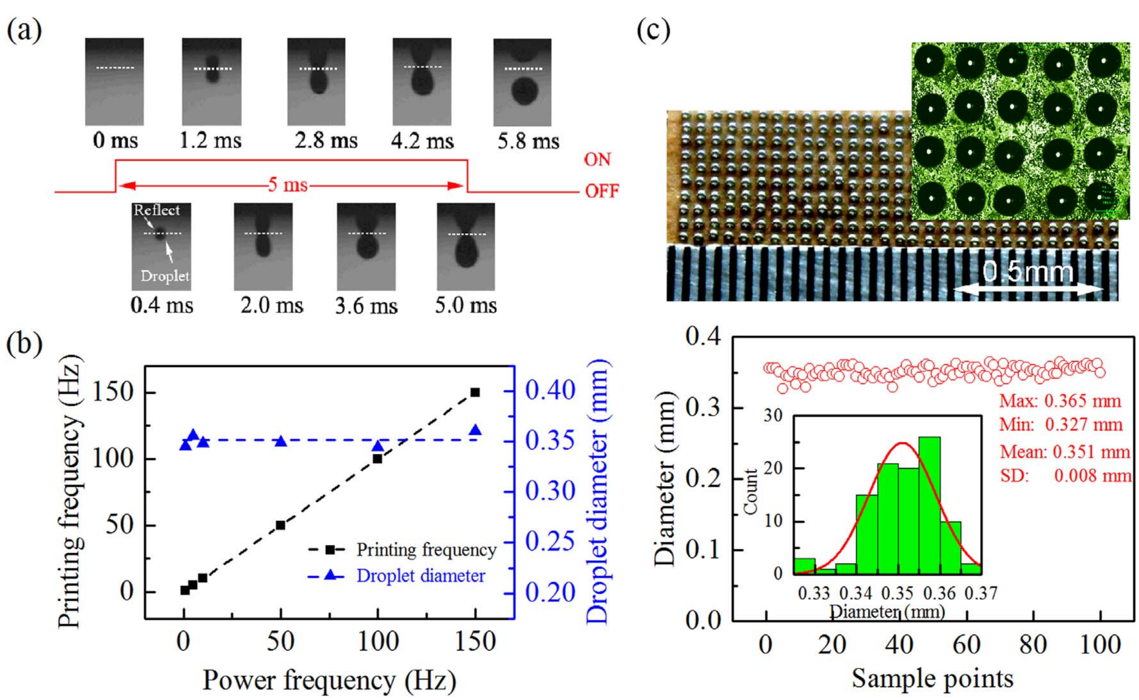

Fig. 2. (a) Evolution of mercury droplet jetting out of the nozzle under 5 ms pulse width of applied voltage. (b) The printing frequency and droplet diameter versus power frequency. (c) Experimental analysis of the printed droplets.