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Electrohydrodynamic jet printing of micro-optical devices

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Abstract

The Electrohydrodynamic-jet (E-jet) printing process combines high resolution printing with a large variety of printing materials, making E-jet suitable for applications ranging from flexible electronics to high resolution biosensors. In this article, we explore a novel E-jet printing application fabricating high-resolution micro-optical devices. Examples given are a microlens array, an optical waveguide multiplexer, and a multi-refractive index diffraction grating. Additionally, this work presents the potential use of a multi nozzle printhead to perform low cost and flexible heterogeneous integration of multiple materials with different optical properties.

Keywords: Electrohydrodynamic-Jet printing; Additive manufacturing; Optics; Microfabrication

High resolution printing has become a viable technique for nano/micro-scale device fabrication. In 2007, Park et al. introduced the E-jet printing process and reported various applications primarily in the area of printed electronics [1]. Further work [2] made process improvements including the resolution, reliability, and throughput. Since E-jet is very flexible with respect to printing materials, including heterogeneous integration [3], there is a wide array of promising opportunities for printed electronics and biological sensing applications [4–7]. This article explores a new application domain; the use of E-Jet printing for fabricating micro-optical devices.

Micro-optical devices are used to emit, collect, distribute or modify optical radiation. They have become a ubiquitous part of modern technology and provide solutions to many technological challenges including: visual displays, spectroscopy, medicine, and biophotonics [8]. Micro-optical devices are usually fabricated by either laser ablation or lithographic processes. Some optical devices require a considerable amount of blank material removal and, consequently, inkjet printing has been considered as an additive fabrication process [9,10]. Despite the potential benefits of ink-jet printing, many photonics applications require a much higher integration density which exceeds the available feature resolution for inkjet printing. This motivates the consideration of E-Jet printing for fabricating high resolution micro-optical devices.

The physics of the E-Jet printing process is detailed in [2,11]. A potential difference between the nozzle and the substrate is applied. An electric field is then generated at the tip of the nozzle causing a concentration of charge on the pendant drop emanating from the tip. This concentrated charge generates shear stress, deforming the meniscus to a conical shape termed a Taylor cone [16]. The shear stress generated by the charge overcomes the ink surface tension; thereby releasing a droplet.

Fig. 1 illustrates a multi-nozzle E-jet system whereby a multiple simultaneous depositions can be achieved to greatly increase throughput. This toolbit consists of three nozzles in a planar arrangement. The middle nozzle is held stationary and acts as a positioning reference for the two outer nozzles. The outer nozzles are mounted on three degree of freedom miniature linear stages to compensate for any translational misalignment. The inset displays the

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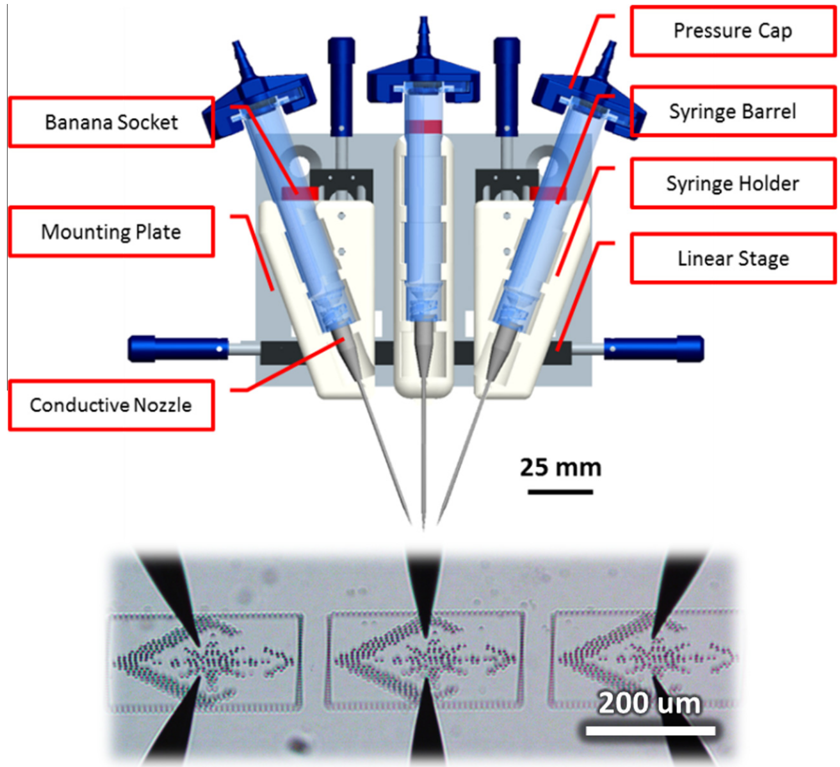

Figure 1. The design of a multinozzle toolbit. The inset shows the experimental setup after the three collocated nozzles successfully printed identical patterns.

experimental setup after the three nozzles successfully printed identical patterns. Each nozzle can be individually controlled and may hold identical or different materials depending on the printing applications. Further system details can be found in [12].

The following section, 'E-Jet printing of micro-optical devices,' details individual types of micro-optical devices that can be fabricated using the system of Fig. 1. Subsequently, a section on 'Conclusions and future work' provides a brief conclusion and outlines future opportunities.

1. E-Jet printing of micro-optical devices

This section presents 3 distinct examples of micro-optical components that can be fabricated through E-Jet printing. These are: a microlens array, an optical waveguide splitter, and a refractive diffraction pattern.

1.1. Micro-lens array

Microlens arrays are commonly used for concentrating photons on a photosensitive target. They improve the optical fill factor of CCD sensors and increase the conversion efficiency of PV cells. These passive micro-optical components are also used as free-space optical interconnects for a highly parallelized intra-chip communication [9,13]. High density sensor arrays for imaging, which can be found on the latest SLR cameras, require a very high spatial resolution to deliver a good image quality. Additionally, to prevent local aberrations, it is critical for all of the microlenses to be uniform in size.

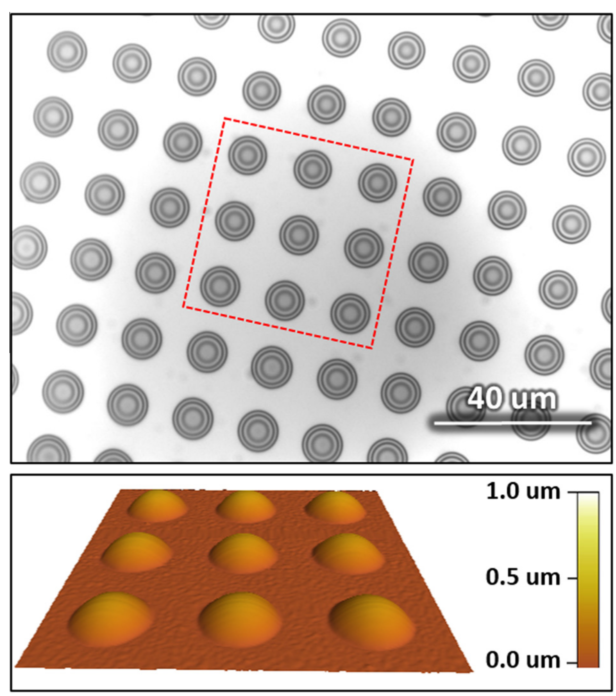

Figure 2. Optical microscope image of the E-Jet printed microlens array. The AFM image demonstrates the uniformity of the lens morphology.