Additive manufacturing platform for high precision printing

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The aim of the project is to develop technology for printing transparent high resolution and high flatness structures. In particular, this platform would be suitable to print complex optical elements such as for example curved ridge waveguides and arrays of aspherical microlenses which is currently not possible with existing

The key elements of the manufacturing platform are shown in fig .1:

1. Controlled droplet ejection via a choc wave delivered by focusing nanosecond pulses near the exit of a micro-capillary filled with a transparent liquid (light polymerizable resin or epoxy or hydrogel). A choc wave is produced by focusing the light pulse that ejects droplets. The location of the focused pulse inside the capillary can be moved electronically along the pength of the capillary and across its section.
2. Polymerization i.e hardening of droplets is controlled by focused illumination (e.g. 405 nm). Focused illumination is created by controlling the wavefront of light coupled in a multimode fiber. The diameter of the micro-capillary and multimode fiber is of the order of 0.5 mm which allows them to be side by side in close proximity so as to have unobstructed access to the droplets for the polymerizing light.

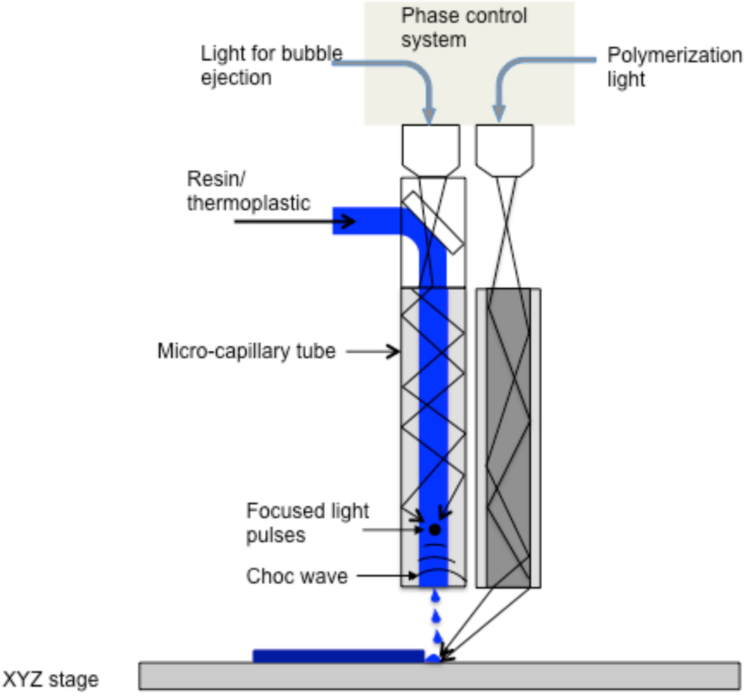

Fig. 1: schematic of the additive manufacturing platform

3. The multimode fiber also serves as a high resolution imaging device to observe and control the printed structures [1].

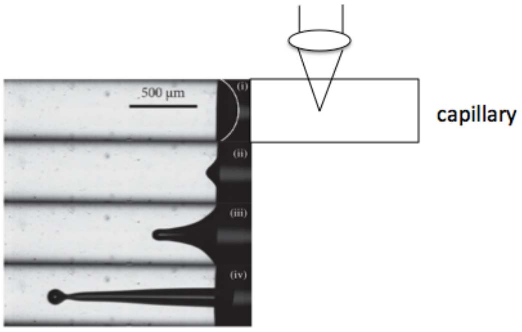

Fig. 2: droplet ejection from a capillary by focusing light [2].

Recent research results reported by a Dutch group [2] has demonstrated the ejection of droplets by a focusing 6 ns pulse beam at 532 nm in a capillary. The beam was focused orthogonally to the length of the capillary as fig. 2 illustrates. The researchers reported an ejected droplet diameter one order of magnitude smaller than the capillary diameter (5 µm droplet for a 50 µm diameter capillary). 20 µJ per pulse was sufficient to eject a droplet at a speed of 490 m/s! They reported an asymmetry of the ejection location when the focus was at a distance less than the diameter to the end of the capillary.

With the proposed system, it will be very interesting to investigate the parameters of ejection (speed, size, direction, position, focused energy) as a function of the excitation spot location which can be brought along the capillary length and placed anywhere electronically by changing the phase pattern on the proximal side [3,4]. Focusing light through a 100 µm diameter capillary filled with water has been demonstrated in the laboratory (unpublished results). The Dutch research [2] focused on high speed droplets for applications in needle free drug injection. For additive manufacturing, a high kinetic energy of the droplet is not desirable because the droplet would splatter on the target and also would be too energy intensive. There are a number of parameters to tune, such as liquid viscosity, capillary diameter, fluid density, surface tension and optical pulse energy, to eject a droplet with low ejection speed. The droplet size reported (5 μm) in [2] seems promising to produce micrometer resolution smooth structures.

For example, the ejection speed was shown to be dependent on capillary diameter and pulse energy. A 500 μm diameter capillary generated a droplet speed of 21 m/s and 55 m/s when a focused pulse of energy 365 μJ and 650 μJ were used respectively. For comparison, this droplet speed is similar to the speed of ink droplets in continuous inkjet technology. The parameters required for hardening the droplets at impact or in flight via photopolymerization will need to be investigated. The same multimode fiber will be used to provide the imaging capability (e.g fiber bundle with white light illumination – and focusing with a fiber bundle has also been realized in the laboratory) to investigate the printed structure in real time.

In summary the proposed additive manufacturing platform provides a novel reconfigurable droplet delivery system (variable size, speed) coupled with reconfigurable light polymerization (spot size, location) to make the 3D structure.

The work will be divided in 1. Developing the fluid delivery system with capillary, investigating the dynamics of droplets ejection 2. Implementing the steerable, reconfigurable curing light and imaging system 3. Coupling system 1. and 2. to form and characterize structures.

[1] Papadopoulos et al., Farahi, S., Moser C., Psaltis D., *Focusing and scanning light through a multimode optical fiber using digital phase conjugation*, Optics Express, Vol. 20, Issue 10, pp. 10583-10590, 2012.

[2] Y. Tagawa et. Al, *Highly focused supersonic microjets*, Phys. Review X 2, 031002, 2012.

[3] Papadopoulos I., Simandoux O., Farahi S., Huignard J-P., Bossy E., Psaltis D., Moser C., *Optical resolution photoacoustic microscopy by use of a multimode fiber*, Appl. Phys. Lett., Vol. 102, Issue 21, pp. 211106, 2013.

[4] Farahi S., Ziegler D., Papadopoulos I., Psaltis D., Moser C., *Dynamic bending compensation while focusing through a multimode fiber*, Optics Express, Vol. 21, Issue 19, pp. 22504-22514, 2013.