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3-Dimensional Hydrogel Printing via Electron Crosslinking

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Additive manufacturing has gained significant attention in the last few years. We have seen improvements in terms of speed, resolution and diversity of materials that can be 3D printed [1]. Typically, 3D printing of hydrogels is brought about by injection-type printers and optical curing [2]. The resolution of such an optical curing has been of the order of 0.1 mm to 1mm.

On the other hand, lithographic patterning using electron beam is widely available and a rather common technique which can be used for beam induced triggering of the cross-linking process [3-5]. While this technique is currently used for 2D pattern formation, there is a shortage of data on the 3-dimensionality of the features formed using electron beam. Although it is clear from Monte-Carlo electron trajectories simulations (Figure 1 Top panel) that the range of electron beam into the curing matrix can be controlled via the energy of electrons and the depth of interaction can range from 10's of nanometers to 100's of microns. This handle on the feature depth can be leveraged for complex patterning.

We show preliminary results of hydrogel patterning and formation of 3-D features. Hydrogels themselves constitute an important category of materials finding applications as substrate for biomaterials, as biocompatible parts for implants, for encapsulating biomaterials for further characterization etc. The parameter space for patterning including beam current and energy is explored to study their effect on the feature size.

The material used here is Polyethylene (glycol) Diacrylate (PEGDA) with Irgacure as the initiator. Spot illumination mode is used for a dwell time of 100 ms for 3, 5, 10, 20 kV electron energy (Figure 1 Bottom panel). We demonstrate that the electron beam cured samples can be controlled to less than a micron width and height (Figure 1 Inset top). Further the feature width is a function of current for low current values and saturates for higher values. This is indicative that for low currents, the minimum threshold for crosslinking is not achieved in the entire volume of interaction.

In conclusion, this technique has potential to allow for an order of magnitude improvement in the resolution of the 3D printed parts over the conventional optical printing of the hydrogels.

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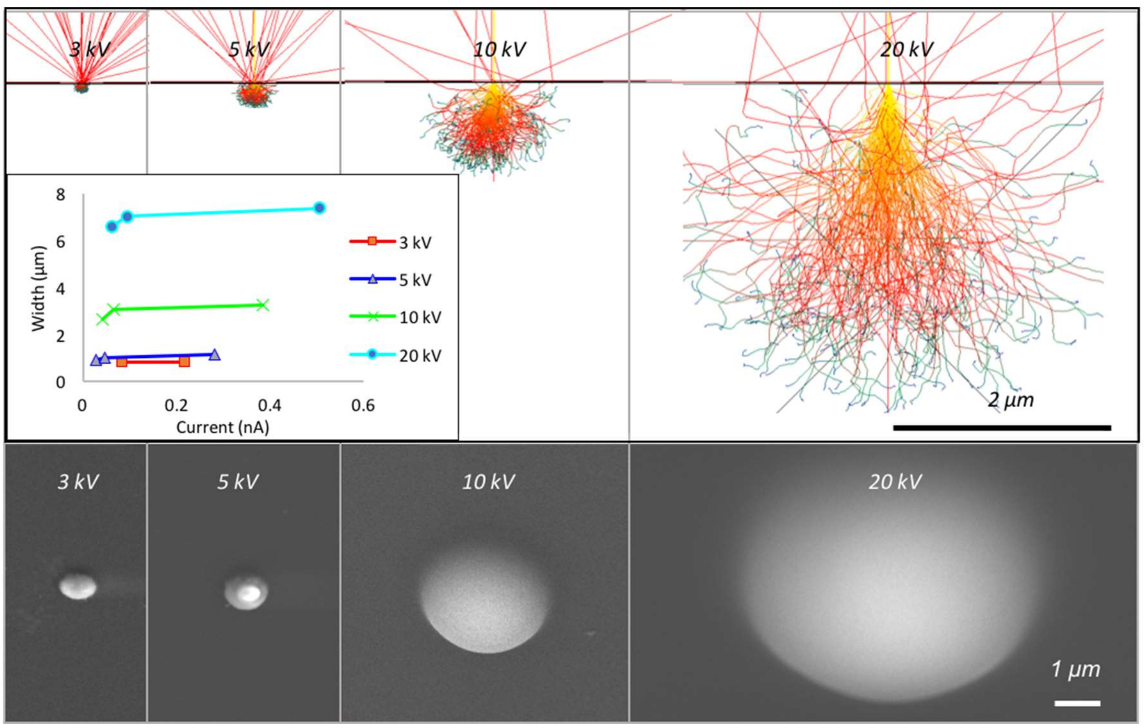

Figure 1. (Top) CASINO simulations with 50 nm Silicon Nitride window, (Inset top) Width of cured PEGDA upon spot illumination for 100 ms for different energies. (bottom) SEM images for features formed at different energies.

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