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Localized Laser Pyrolysis of SU-8 by Addition of Absorber

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Here, we present a method for direct laser writing of carbonized lines in SU-8 by adding an absorber to the photoresist. We have successfully achieved conducting lines down to 30 µm in width with accurate pattern control.

Recently, several research groups have reported work on local laser pyrolysis (LLP) of polymers, mainly polyimide (PI), commercially sold as Kapton® [1]. Luo *et al.* demonstrated LLP for fabrication of flexible electronics in PI [2], while Lin *et al.* applied LLP for preparation of microsupercapacitors (µSCs) in PI, as well as testing of the laser-pyrolysability of various other polymers [3]. Here, we investigate LLP of SU-8, which is an epoxy based photoresist already widely used in micro- and nanofabrication and which has the advantage of enabling fabrication of very tall structures with very fine features [4]. We achieved this, by adding an absorber to the SU-8, which enables light absorption at the 800 nm wavelength range and writing with a laser (a modified Heidelberg µPG101IR direct laser writer) with a very narrow peak intensity around 806 nm wavelength. The absorbed light is converted into heat, which locally pyrolyses the SU-8 and converts it into carbon.

The absorber (FujiFilm Pro-Jet 800NP) is dissolved in cyclopentanone and mixed with SU-8 2035 (MicroChem) before being spin-coated onto a boron glass wafer to a thickness of 10 µm (Fig.1a). After baking out the solvents, first on a hotplate at 75 °C for 30 min and then in an oven at 90 °C for 24 hrs., the desired pattern is written in the SU-8 at laser powers ranging from 20-800 mW and writing speeds of 0.1-4 mm/s (Fig.1b).

The width and depth of the grooves (lines) are then evaluated using optical microscopy and optical profilometry. Raman spectroscopy is used to confirm that the lines are indeed carbonized. The laser affects only the absorber-modified SU-8, while SU-8 without the absorber incorporated remains completely unscathed by the laser. Furthermore, purging with nitrogen while writing aids the pyrolysis process and lowers the energy threshold needed to achieve carbonization of the substrate (Fig.2). The thickness and pyrolysed profile of the lines is determined using FIB-SEM. Fig.3 shows that the lines have a half-elliptical cross-section and the pyrolysis goes all the way down to the boron glass substrate.

A dollop of conductive paste is applied at either end of the lines to obtain an ohmic contact and then the electrical resistance through the lines is measured using a multimeter with two probes (Fig.1c). It appears that the conductivity of the lines can be controlled by the laser power and writing speed, and currently, estimated conductances of 0.5-2.5 S/cm can be achieved at writing speeds of up to 1 mm/s and power < 100 mW (data not shown here). The resistance increases linearly with the line length as would be expected (Fig.4) and the resistance is affected by intersections of lines such as the ones shown in figure 5. We are currently investigating the stability and reproducibility of the process, as well as the influence of the various process parameters on the laser-written carbon lines.

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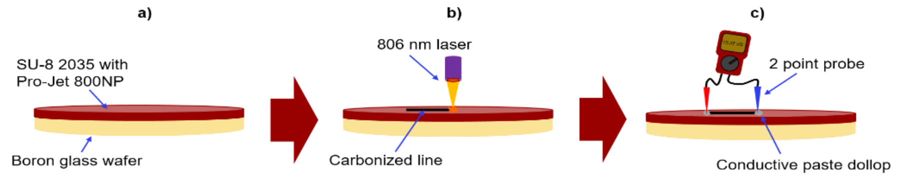

Figure 1. Process overview. **a)** SU-8 2035 is mixed with Pro-Jet 800NP diluted in cyclopentanone and spin coated onto a boron glass wafer to a thickness of about 10 µm. **b)** After baking at 90 °C for 24 hrs., the substrate is written on using a continuous wave laser with a wavelength of 806 nm. The locally absorbed laser power is converted into heat which pyrolyses the polymer locally. **c)** The resistance through the written carbonized line is then measured using a multimeter with two probes.

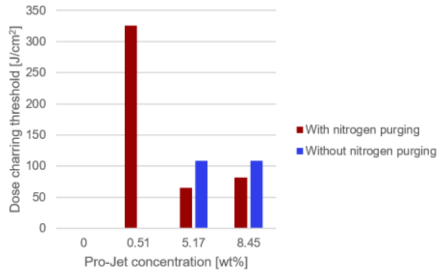

Figure 2. Dose thresholds required for complete charring of lines written on substrates with various concentrations of Pro-Jet 800NP in the resist. Without the Pro-Jet, the laser is unable to pyrolyse the substrate. Purging with nitrogen while writing lowers the dose threshold required for complete charring.

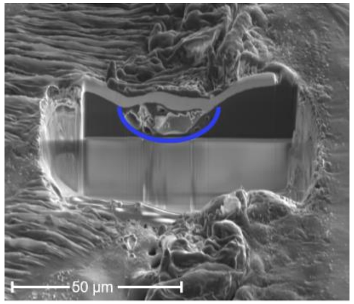

Figure 3. FIB-SEM image of the cross-section of a line written with the laser in the absorber-modified SU-8. The image is taken at 52° tilt angle. We expect that the conducting part of the line is confined within the blue half-ellipsis, and that the rugged part on top of the line is melted polymer that has flowed in from the sides.

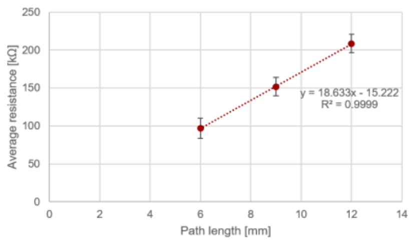

Figure 4. Avg. resistance vs. path length. St.dev. (n=7) is used for the error bars. The resistance of the lines is proportional to the length.

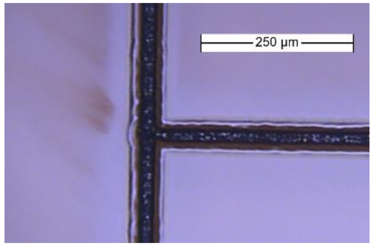

Figure 5. Optical microscope image of two intersecting lines. Current could pass through the junction without any added resistance.