LASER WELDED POLYANILINE CIRCUITS

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ABSTRACT

This paper reports a simple method for the integration of highly intricate conducting polymer electrodes into polymer microchips. We have previously made circuits from the conducting polymer, polyaniline, and used these as high voltage electrodes in microchip electrophoresis [1]. The circuits were patterned via flash lithography in which unmasked regions of the polyaniline were welded into an insulating material upon exposure to a high intensity burst of light from a camera flash. A detailed examination of the welding allowed us to identify the wavelengths crucial for the welding, enabling the use of a diode laser for the fabrication of intricate polyaniline electrodes as small as 10 μm. Direct writing with the laser and a computer-controlled xy stage allowed the fabrication of electrodes for contactless conductivity detection. Furthermore, the non-linear relationship between electrode width and resistance enables the creation of non-linear voltage gradients, and when placed on a flexible substrate, the creation of dynamically variable resistors.

KEYWORDS: Conducting polymer, laser welding, conductivity detection,

INTRODUCTION

In recent times there has been a strong trend towards developing more highly integrated microfluidic devices for a range of Lab-on-a-chip applications. The drive is ultimately towards the development of cheap single-use devices, however currently those that contain integrated metal electrodes are still too expensive. One way in which the cost could be decreased is to use cheaper materials that can be patterned into conducting circuits via a simple process. We have previously demonstrated the simple patterning of electrical circuits using flash lithography to create high voltage electrodes for microchip electrophoresis [1]. One of the limitations was the ability to pattern fine features (<50 μm in size) due to the poor collimation of the camera light and films thicker than 5 μm due to the low intensity of the flash. In trying to understand the phenomena of flash-welding, we discovered that polyaniline is welded upon exposure to light with a wavelength greater than 570 nm allowing it to be patterned with a 635 nm laser [2].

EXPERIMENTAL

Polyaniline was synthesized using the rapid mixing technique as described previously [3]. Thin films of PANI were prepared by drop casting a suspension of 4 g/L de-doped PANI onto an acrylic or PDMS substrate, using 40 μL/cm^2. Polyaniline films with thickness ranging from 3.6 μm for 2 layers, and 14.5 μm for 8 layers. Prior to casting, each substrate was cleaned by soaking in 0.2 M NaOH for 5 min with mild agitation before rinsing with running MilliQ water followed by drying with lint-free paper towel. Directly before casting, the substrates were treated for 2 min with forming surface plasma (BD-20ACV, Electro Technic High Frequency Generator, USA). The films were air-dried on a level bench at room temperature for 2 hours before a second coat was applied and dried in a similar fashion. The film was then doped by dipping into 1M HCl to convert the polyaniline from the non-conducting PANI emeraldine base to the conducting emeraldine salt.

Using a simple setup in which a 50x microscope objective to focus light from a 635 nm solid-state laser onto a computer controlled XY stage (Figure 1), 10 μm wide non-conducting features can be welded enabling complete electrical insulation between two conducting regions of polyaniline (figure 2). The green colour of the polyaniline film in Figure 2 is indicative of the conducting emeraldine base form, while the dark colour indicates the welded region.

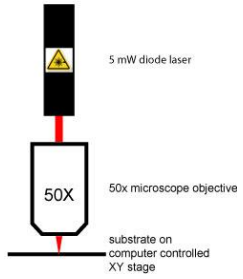

Figure 1: Schematic of the apparatus used for direct laser welding of polyaniline circuits.

For PDMS deflection studies, polyaniline was coated on a 50 μm thick piece of PDMS and placed on another PDMS substrate with 100 μm x 30 μm channels suitable for application of pressure using Quake valves [4].

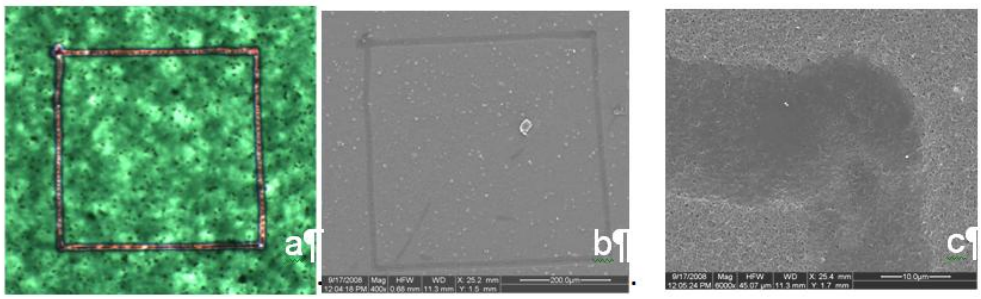

Figure 2: (a) light microscope image and (b and c) SEM of polyaniline film welded with a focused 635 nm laser.

RESULTS AND DISCUSSION

The use of a computer controlled XY stage allows complex and intricate patterns to be created in thick polyaniline films. Figure 3 shows the fabrication of a series of 5 contactless conductivity detectors created on a 50 mm x 70 mm acrylic microscope slide. Laser welding is used to create non-conducting regions around the electrode, including the detection gap which is a small region of non-conducting material between the source and detection electrodes. Studies revealed that a single 10 μm pass of the laser was sufficient to create a completely insulating region between the two detection pads. When combined with a thin insulating layer of dry film resist between polyanilne electrodes and the microchannel, this allows the creation of contactless conductivity detections with dimensions smaller than have otherwise been reported.

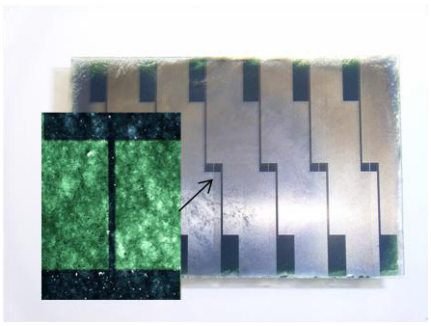
Figure 3: A 50 x 70 mm plastic microscope slide with 6 patterned contactless conductivity detectors with detection gaps from 60 – 120 μm. The insert showing an optical micrograph of the detection electrodes. The green area is the non-welded conducting polyanilne film.

The flexibility offered in patterning the polyanilne film also allows the creation of geometrically irregular electrodes. An image of an irregular shaped electrode is shown in Figure 4, in which the width of the conducting central polyanilne wire is varied in a continuous fashion from 50 μm to 1 mm. This allows the unique generation on non-linear gradients as the resistance of the polyanilne electrode is strongly dependent on the width. This is depicted in Figure 5, which shows the change in resistance of a polyaniline film as a function of width. To achieve this data, a 2 mm polyaniline film was continuously shaved in 10 μm increments with the laser and resistance measurements recorded with a multimeter. The resistance changes by a factor of 100 upon changing the width of the polyanilne from 20 μm to 2 mm. This type of electrode will have application in the generation of non-liner electric fields, and more specifically, in electric field gradient focusing.

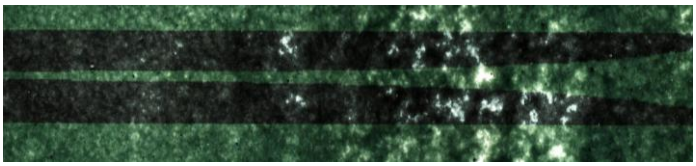
Figure 4: geometrically irregular polyanilne electode (inner green region). The electrode width is varied continuously from 50 μm on the left to 1 mm on the right.

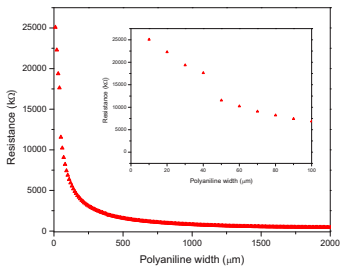

Figure 5: Variation in polyaniline wire resistance as a function of its width. This data was collected by sequentially shaving the polyaniline thinner with the laser.

The ability to pattern polyanilne on flexible materials, such as PDMS, allows the creation of sensors. This is illustrated in Figure 6 which shows the change in resistance of a polyaniline film placed on a 50 μm thick piece of PDMS above a quake valve. The figure shows application of 50 psi for 10 s, with 10 s in between each pulse over the period of 10 min. A 25-fold change in resistance is obtained with deflection of the PDMS. The response time is rapid, less than 1 sec, and the film is stable for a number of repetitions.

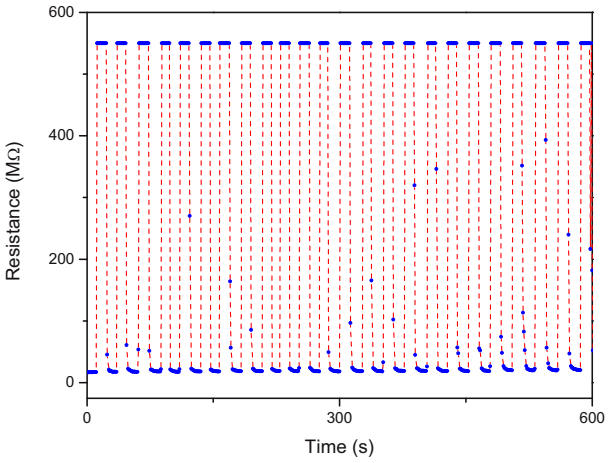

Figure 6: Variation in polyaniline wire resistance on top of a quake valve. The valve was actuated for 10 s, every 20 s, at a pressure of 50 psi. Resistance was measured with a multimeter.

CONCLUSION

Conducting polymers offer a versatile solution to the integration of electrical components into lab-on-a-chip devices. They can be easily deposited, simply patterned, and offer a wide range of unique properties that will have application in the field.

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