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Introduction

Conductive polymers (CP) has the potential to form the basis of a new generation of active devices. The main advantage of CP is low cost, easy processing and integration with other types of polymers. To exploit this potential methods for micropatterning of CP has to be developed. Already extensive research is being conducted in the field, and methods like ink-jet printing have shown to produce fast and reliable patterns, with relative low resolution however. Other methods like soft lithography yields high resolution but is expensive to employ in a mass production facility. Thus a need is present for a method which produces fast high resolution patterns in CP. A new and fast method has been developed [1], where gel stamps impregnated with hypochlorite is used for spatially confined delivering of reactants leading to a patterned conductive polymer (see figure 1).

Hypochlorite & Agarose

It is known from literature that hypochlorite is an excellent deactivation agent for conductive polymers [2]. In the current work, the used CP is poly(3,4-ethylenedioxythiophene) (PEDOT). The loss of conductivity is caused by oxidation of the thiophene ring to thiophene-1,1-dioxide followed by ring-opening and splitting off of SO_4^{2-} (see reaction scheme below). Initially when exposed to hypochlorite the conductivity of the polymer is reduced with a factor of approximately 10^7 . This is followed by a physical etching of the CP.

Agarose is a polysaccharide forming mechanically stable gels even with a water content of 85-98 w%. Due to the high water content, the internal diffusion of ions is relatively fast making it a suitable material for delivery of ionic species.

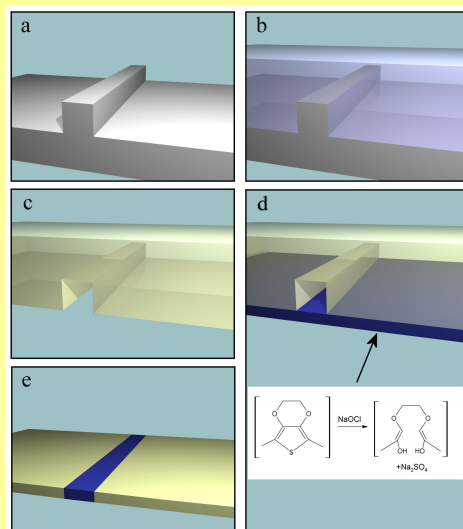
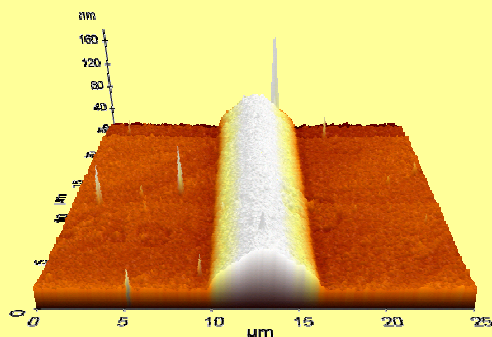
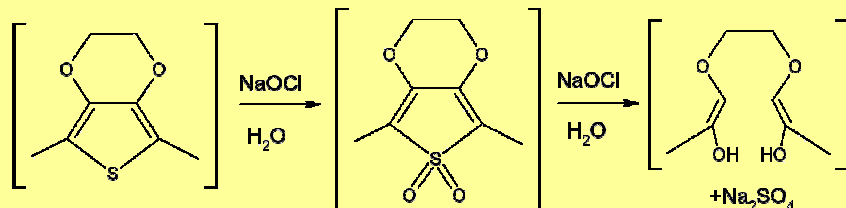


Figure 1: The individual steps in the patterning methods:

A) Photoresist is patterned with conventional lithographic techniques to present a surface relief corresponding to the final pattern.

B) The hot agarose gel is molded against the photoresist pattern to yield the inverse pattern.

C) The agarose stamp is cooled, peeled off the master and impregnated with sodium hypochlorite.

D) The agarose stamp is placed on the PEDOT surface, and the hypochlorite diffuses to the surface in areas of contact leading to spatially defined deactivation of the PEDOT.

E) After a few seconds the stamp is removed and the sample rinsed with water.

Above: The oxidation of PEDOT leaves to a ring-opening of the thiophene causing loss of conductivity.

Left: Atomic force microscopy of PEDOT deactivated with hypochlorite. The non-deactivated wire is approximately 60 nm higher than the deactivated area. The initial thickness was 100 nm showing that the hypochlorite have removed a significant part of the polymer.

Minimum feature size.

The minimum feature size was tested by fabricating a geometry where two contact pads were connected by a thin wire. The resistance of the wire could then be measured using a four point probe, where each pad was contacted by a current and potential electrode. This is presented in the figure 2:

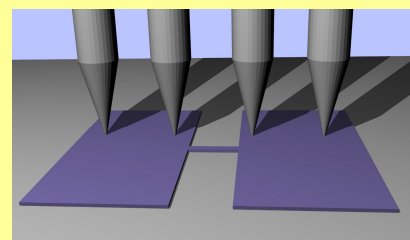


Figure 2: The setup used to measure the conductance of the produced wires

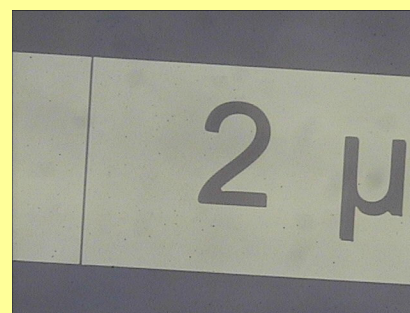


Figure 3: A 2 μm wire produced with agarose stamping.

The wires were produced with a width of 2, 4, 6, 8, 10, 12, 15, and 20 μm. The conductance of the wires relative to the 20 μm are plotted in figure 4. The plot were used to predict the edge effects caused by diffusion of the deactivation agent in the PEDOT layer.

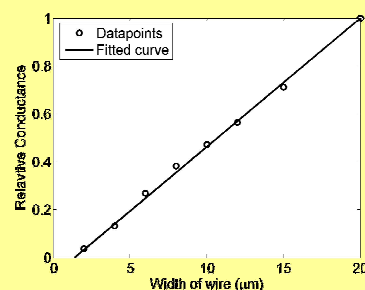


Figure 4: The relative conductance of the PEDOT wires. A linear fit to the measurements predicts zero conductance at a line width of 1.5 μm, giving an edge effect of 0.75 μm.

References

- [1] T. S. Hansen, K. West, O. Hassager, N. B. Larsen, *Submitted for Advanced materials*
- [2] Y. Yoshioka, P. D. Calvert, G. E. Jabbour, *Macromol. Rapid Commun.*, 2005, 26, 238