Implantation of carbon nanotubes in photoresist micro-channels for heat transfer applications

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IMPLANTATION OF CARBON NANOTUBES IN PHOTORESIST MICROCHANNELS FOR HEAT TRANSFER APPLICATIONS.

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Introduction.

One of the most important applied research field associated to microfluidics deals with heat exchangers, mixers or reactors. The future electronic devices will contain more and more components, causing an increasingly heat generation that can harm internal parts of the device and requiring innovative cooling methods. Since the publication of Tuckerman and Pease [1] who first used silicon microchannels as heat exchangers, there has been a lot of works for devices including microsystems that circulate a fluid to draw heat from chips. From a heat exchange point of view, using a liquid is better than air. But the reduction of the hydraulic diameter of the microchannels involves a dramatic increase of the pressure drops. So, to assume the flow rate of the liquid, the system has to be equipped with macroscopic pumps and the benefits of reducing the size of the exchanger are lost. Using nanofluids as cooling liquid systems is a new exciting alternated way studied by many researchers [2]. Nanofluids refer to a two-phase mixture, that is a liquid in which fine metallic nanoparticules less than 50 nm in size are dispersed. Of course, easily available carbon nanotubes (CNT) are an extensively used tool for such applications. A experiment under test is to incorporate CNT into thermal grease that sits between a microprocessor and a heat sink [3]. On the one hand, the CNT conduct heat extremely well, are very small, can be suspended in liquids or polymers. One the other hand, CNT are superior thermal conductors by themselves but because of high thermal boundary resistance between the tubes and the other elements, some authors argue that they cannot exhibit the same level of high conductivity when integrated into other materials [4].

So, using a liquid involves many challenges, and industry would rather use air as a cooling method. Mechanical researchers at Purdue University have presented a technology that uses a nano lightning to create tiny wind currents [5]. With the help of CNT used as charged elctrodes, ionized air molecules cause a 'Corona wind' effect with a relative low voltage. A periodic switching makes the ionized cloud move and makes the neutral molecules breeze.

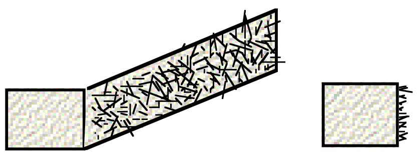

Figure 1. Nanostructured wall of a microchannel with carbon nanotubes in order to improve the heat exchanges.

We present here a device designed to improve the effective heat transfer behaviors of fluids, that is based on the use of CNT as mechanical nano wings. The thermal conductance of a wall is the product of the area by the thermal exchange coefficient, that depends upon the nature of the fluids. Our idea is to increase the exchange area by implanting CNT into the walls of a microchannel, as descripted in figure 1.

Microfabrication of the device.

Classical technologies used to perform CNT are ineffective for our application, because the CNT cannot stay when submitted to a strong stream. We mould the CNT into a photoresist and after a chemical development, the microchannel is revealed. Exceeding CNT are removed and only the strongest anchored nanowings remain. This is possible because the CNT are transparent for the UV radiation used during the micromachining steps. The experimental steps are shown in figure 2.

First, dispersed nanotubes in a thin volume of solvant are gradually mixed with a SU8 negative photoresist (Fig. 2-a). The SU8 photoresist is an alternative for the micromachining of 3D structures as microchannels, because of its high aspect ratio. The choice of the type of photoresist is balanced by the need of several micrometer high microchannels and by the high viscosity of such a resist, that can harden an homogeneous mixture of the CNT. We used SU8 2015 photoresist to reach 30 µm high walls and to perform a good mixture.

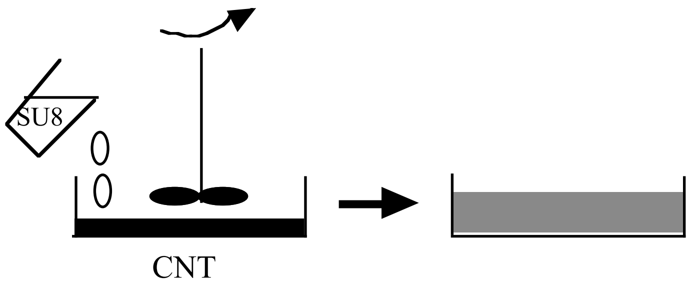

Figure 2-a. Carbon nanotubes and SU8 photoresist are mechanically mixed.

This mixture is spread and performed following the usual steps used with a classical SU8 photoresist (soft bake, insolation, post exposition bake, development etc …)

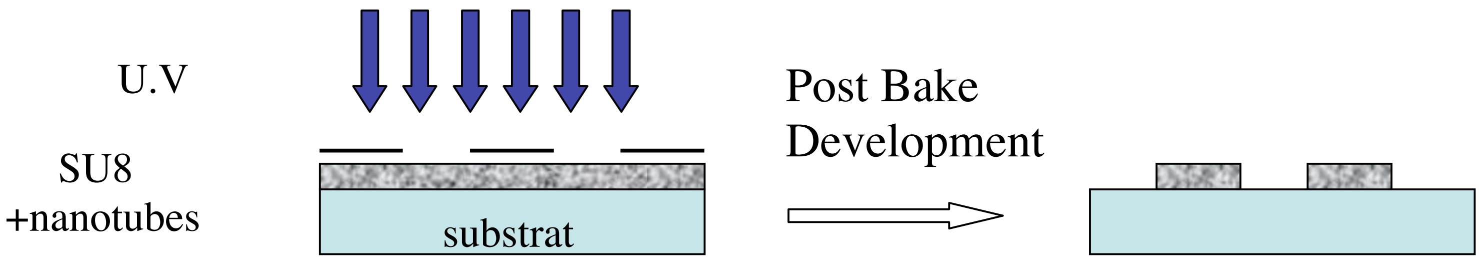

Figure 2-b.

Fine adjustments with the volumic concentration of the CNT into the SU8 must be found. Too much CNT concentration arises the viscosity of the mixture and the final heigth of the structure may be 200% higher than predicted. Concerning the UV exposure, the CNT are really transparent for such wavelengths and the exposed parts remain. A micrograph of the wall of such a microchannel is shown in figure 3. Anchored carbon nanotubes are clearly apparent, but still coated with a residual photoresist. A short O_2 plasma reactive ion etching eliminates the coatings.

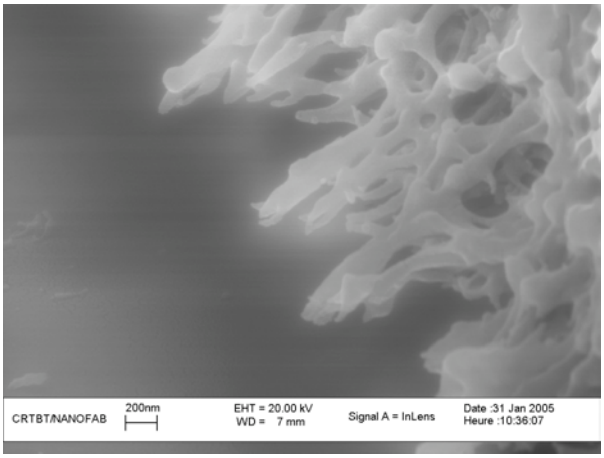

Figure 3-a. Zoom of the wall of the microchannel

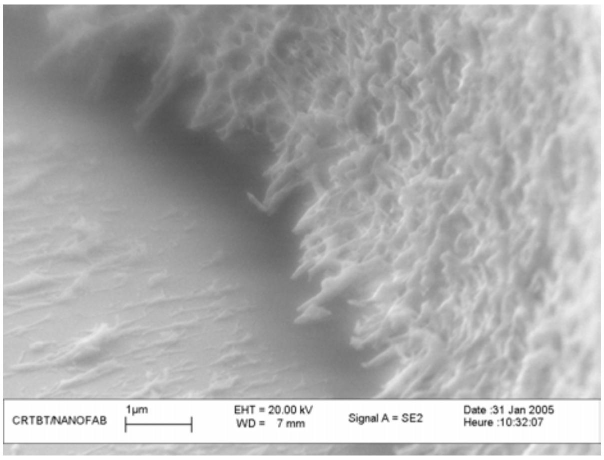

Figure 3-b. Nanostructured wall with emerging carbon nanotubes.

The bonding of the microsystem is made by pressing a Pyrex cap with photoresist onto the microchannel [6].

Experiment are now under test in order to quantify the thermal behaviour of the CNT doped microchannels. Two designs are tested. The first ones have metallized walls to improve the heat evacuation. The second ones have polymerized walls and are used as heat regenerators.

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