

Sub-micrometer Network Fabrication for Bacterial Carriers and Electrical Signal Transmission

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Abstract. A compact platform for producing sub-micrometer 3D interconnects and networks for bacterial carriers and electrical signal transmission is briefly presented. The platform is composed of a dispensing system using polyurethane doped with silver nanoparticles, curing system controlling the polymerization process by emitting UV light, and an annealing system which is used to remove the cured resin and sinter the silver nanoparticles to reach suitable resistivity. We also add a video microscope to help the optimization of the process.

Keywords: 3D network, nano-interconnection, nano-bio paradigm, robotic platform.

1 Introduction

This paper proposes a method to fabricate conductive micro- and nano-networks with capability of carrying functionalized magnetotactic bacteria on the surface, as shown on Figure 1(a). In this method a robotic platform is used along with a micro dispensing system to produce conductive microfibers with high flexibility. We have improved the conventional direct-write [1] method to control the flexibility of the fibers in 3D, in addition to the fabrication throughput of the fibers. Currently there are different fabrication methods available including polymer extrusion, pulling polymer networks, electro-spinning, photolithography and bottom up techniques [1,2,3,4,5]. All these methods serves a unique way to produce fibers, however important factors such as length, flexibility and the diameter of the fibers are constrained by these methods. Conductive micro and sub micro-wires are used in MEMS, NEMS, interconnect of integrated circuits and fluidic devices.

2 Platform Presentation

The platform uses XYZ stages, having 5nm displacement in open-loop control and $0.5\mu\text{m}$ of repeatability in closed-loop control, allowing any complex 3D motion. The three main system components are described in Section 3, and consist

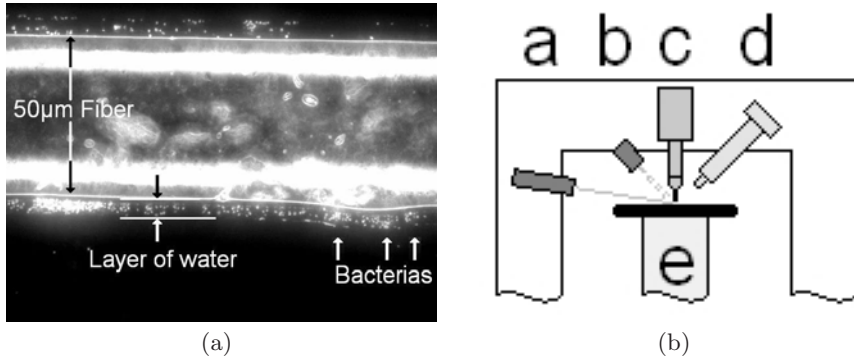


Fig. 1. (a): Bacteria swimming along a $50\mu\text{m}$ diameter fiber. (b): Simple sketch of the platform with 5 elements. **a:** future annealing system. **b:** UV curing system. **c:** dispenser module. **d:** optical microscope. **e:** XYZ robotic stages. a,b,c and d are fixed above the stage on a arch. The sample is fixed on the top of the stages.

of: a dispensing module, a curing system, and a microscope. In the future, an annealing system will also be attached. A simple sketch of the platform is shown in Figure 1(b).

To make networks of conductive fibers, one needs to be able to produce conductive fibers with different shapes. Our approach to make conductive fibers is based on two steps: first a fiber is produced and then is annealed. These two steps are described in the next two subsections.

2.1 Producing a Fiber

Two different approaches are proposed to produce fibers:

1. Each fiber may be pulled from a resin droplet at a special state, called gel point. The gel point indicates the precise moment at which the polymerization makes an infinite polymer network. Dipping a tip in a droplet being at this specific point will allow us to pull this polymer network to create fiber [1,4,6].
2. Each fiber may also be produced by dispensing resin through a nozzle while moving the nozzle over the substrate. As soon as resin is dispensed, it is cured. Depending on the curing speed of the resin different shapes of fiber may occur [1].

In the first approach, the main challenge is to reach the gel point. As the most important dynamic parameter of gel point is the polymerization's percentage of resin, it may be difficult to reach, as explained in Section 3.2. To be able to predict the time at which the gel point occurs, many characteristic of the resin have to be known. The main advantage of this method is the ability to produce fibers of less than 200 nm in diameter [4].

The second approach requires less characterization, as only the viscosity and surface tension of the resin with the chosen substrate and nozzle have to be known. The major drawback is limitation of the nozzle size to reduce the fiber diameter. Fiber diameter is related to the bore size of the dispensing nozzle [1].

We choose to use the first dispensing approach using an epoxy. We choose the epoxy EPON 828 with Triethylenetetramine curing agent. This resin cures in a few minutes at 60°C as shown in Figure 2(a), which is compatible with our application.

2.2 Annealing a Silver-Doped Fiber

Our networks have to carry electric current, and our intended application uses current in the micro-ampere scale. We wish to minimize the power loss in the network by decreasing the resistance of fibers. Resistance of a fiber is calculated with this formula:

$$R = \frac{\rho * L}{A}$$

ρ being the resistivity ($\Omega.m$), L the length (m) and A the cross sectional area (m^2) of the wire. As the cross sectional area of our fibers is less than that of commonly used gold fibers, we need to decrease ρ to maintain similar resistivity. The length is the same order of magnitude in both cases.

To decrease ρ of fiber, we choose to use highly concentrated silver-doped resin. Fibers have up to 70% weight concentration of silver-nanoparticles for two reasons:

First, we use highly concentrated Silver-doped resin at 75% in weight with resistivity of few $\Omega.m$ and can go as low as $5n\Omega.m$ [1]. After annealing we create wire of silver by sintering. The major part of resin is degraded by the annealing.

Secondly, we used silver-nanoparticles as silver bulk resistivity is smaller than gold, being $15.8n\Omega.m$ instead of $24.4n\Omega.m$. Silver-nanoparticles are also cheap and commonly available.

3 Specific Systems

The platform has three specific functions which improve upon existing systems [1,4,6]. One being a video microscope attached to see the process and the two other are described in the next subsection.

3.1 Dispensing Module

We use an EFD Ultra 2400 Series with a 7x piston system to produce fiber according to the first method described in Section 2.1. This system is able to dispense resin of viscosity 1000 Pa.s. at 48 bar. We use a $100\mu m$ diameter nozzle to dispense 500 picoliter droplets in 10 milliseconds. The resulting droplet has $270\mu m \pm 30\mu m$ diameter and $18\mu m \pm 2\mu m$ height and produces an $50\mu m$ diameter fiber.

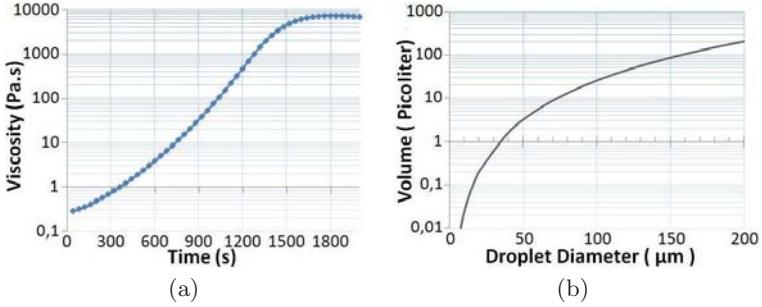


Fig. 2. (a): Measured viscosity of EPON 828 + Triethylenetetramine at 1.2 times the stoichiometric ratio at 60°C in function of time. (b): Calculated droplet's volume at 20°C in function of the droplet's diameter on glass substrate.

To reduce the amount of resin being dispensed, viscosity is the first resin characteristic to be considered. Since epoxy is EPON 828 with Triethylenetetramine curing agent, it cures around room temperature, and as it cures viscosity varies. Viscosity variation at room temperature represents the major drawback using the EPON 828. This prevents easily repeatable polymer flow through the nozzle, and makes it difficult to predict when the polymer will reach gel point. To avoid this viscosity variation EPON 828 has been replaced by polyurethane, which is negligibly influenced by heat at room temperature.

To produce sub-micrometer fibers in order to get the highest networks density possible, we have to produce droplets of a few micrometers in diameter. As shown in Figure 2(b), to get such small droplets, we have to be able to dispense sub-picoliter volume. Since the process of making picoliter volume droplet involves low viscosity fluid [7] it is not possible to integrate this module to our platform.

3.2 Curing System

In this experiment epoxy is used to produce the fibers. However since epoxy is a thermoplastic polymer it cures by heating, therefore it is hard to control the curing state. To solve this problem, we considered two alternative methods. Polymer/solvent curing systems, which cures with evaporation of solvent and UV curing resin, which is negligibly influenced by heat at room temperature. UV light emission is far easier to control than evaporation, so we choose to use UV curing polyurethane. The polyurethane cures best with 365nm UV, and needs 3 $Joules.cm^{-2}$ to cure completely.

4 Future Work

Future work will first focus on making smaller fibers down to few micrometers in diameter. We will use another dispensing system. Again using method 2 of Section 2.1 to make a fiber, we will use an AFM tip carrying a droplet of resin as dispensing system. AFM tip will be glue on the dispenser module. Then we

plan to mix this method with method 1 of Section 2.1 to be able to pull fibers of few hundred nanometers in diameter

Annealing of the fibers using one of the suggested methods: Laser or RF annealing is important. The two suggested annealing technics will be able to provide high temperature with local heating. The annealing part is an essential step to initiate the fabrication at the complex conductive networks.

5 Conclusion

The improved robotic mechanism of this project will enable us to control the fabrication throughput of the fibers. The resulting conductive fibers can then be used as micro carriers for functionalized magnetotactic bacteria. Also the flexibility of the 3D networks can be controlled by proper curing and annealing methods.

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