Fiber Flow Rate Sensors Using Thermally Drawn Multi-Material Fluidic Channel Fibers

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Abstract:

Thermally drawn multi-material fibers with conductive polyethylene (CPE) film incorporated fluidic channels were developed. The initial resistivity of CPE was recorded as 0.35 Ω·m and 0.18 Ω·m after fiber draw. The effect of flow rate on their resistance was observed. The "in fiber" flow sensor can determine the flow rate with a sensitivity of $5.237*10^5$ µV/µL·min^{-1} in the 0-40 µL/min range at bias current 1 mA.

Introduction:

Preforms made up of polycarbonate (PC) slabs and conductive polymer films are drawn into fibers by heating the mold while pulling the preform through the furnace. This method maintains the preform's cross sectional geometry proportionally based on a set reduction ratio (16 to 17 times smaller) [1]. Conductive polyethylene (CPE) film contains carbon black mixed with the polyethylene chain structure. Carbon black is made up of highly conductive fine carbon particles. These particles form conductive pathways in between polymer chains [2].

As water flow cools a resistor, the measured resistance will be less than initially. This change is characterized for a range of flow rates and the flow sensor uses the relation to determine the flow [3]. By containing the process within the fiber, the sensor can be integrated into various applications such as lab equipment, catheters, and fuel injectors [4].

Experimental Procedure:

CPE film was cut to five different lengths, 1-6 cm long and 1.27 cm wide. Resistance was recorded using a four point probe method with four silver paint contact points on each sample [5]. A power supply generated a 0.01 mA current and the voltage across the inner contact points was recorded. The relation between resistance and length denotes the resistivity of CPE film.

Two PC slabs 38.1 mm wide, 381 mm long, and 5.35 mm thick were place on top of another and then wrapped twice with CPE film. The preform is thermally drawn down to a 2 mm wide fiber. CPE is removed so that only one surface is covered to ensure the dimensions of the film. The resistivity of CPE, as a fiber, is determined using the four point probe method with five different lengths at the same current of 0.01 mA.

Two PC slabs individually wrapped three times with CPE film with smaller slabs are placed in between leaving a gap between them. The preform is thermally drawn and reduced to a 1 mm fluidic channel in a 2 mm wide fiber. CPE is removed such that only the resistance of the inner channel layers are measured. Plastic tubing added to both ends to prevent shorting equipment.

A syringe pump induced 0-1000 µL/min of water flow into the channel fiber samples. Flow rate is generated based on the total volume and length of the syringe. Along with the four point probe power supply setup, the resistance was measured at incrementing flow rates.

Results and Conclusions:

The resistivity of CPE decreased from 0.35 to 0.18 Ωm after thermal drawing. Similar sample sets have a consistent resistivity. The thickness and width of the CPE layers in the fiber samples varied greatly. In Figure 2, at lengths beyond 1.5 cm, the conductive pathways become more complex and less linear resulting in a wider range of resistance. In Figure 3, an exponential relation between flow rate and resistance results from the convective cooling process that cools exponentially with flow rate.

This CPE channel design should be only applied in the 0-40 µL/min range because this range produces the most linear data. Within this range we can more precisely determine the flow rate with a sensitivity of, $5.237*10^5$ µV/µL/min, higher than other micro sensors.

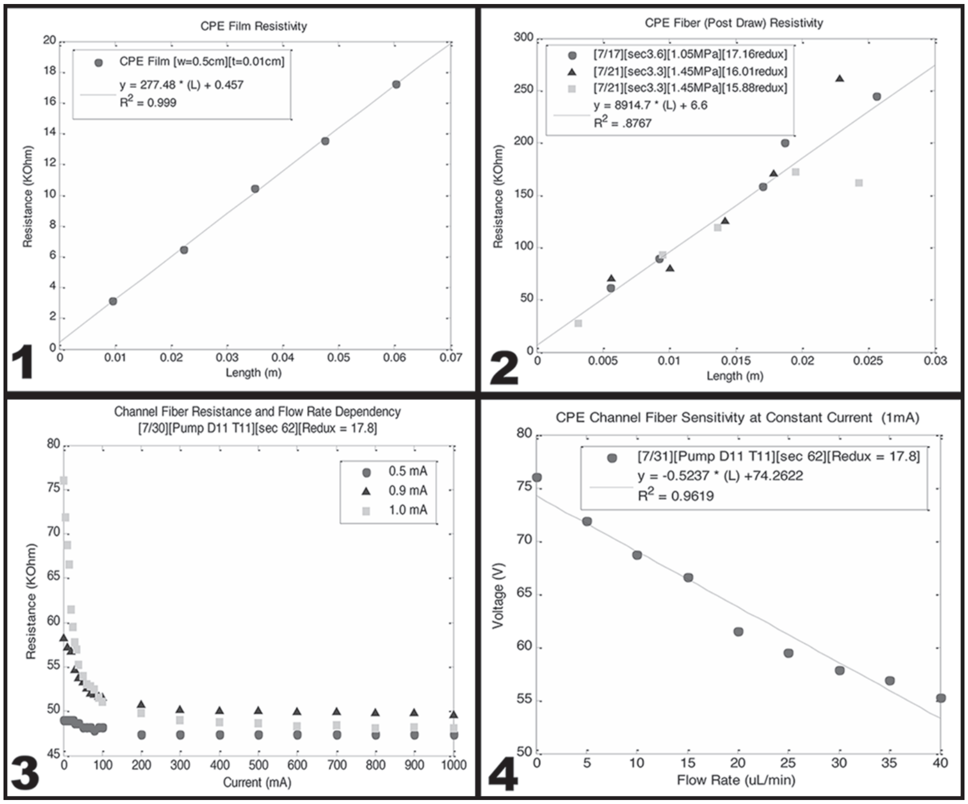

Figure 1, top left: *Resistance values from five different lengths of CPE film. The data closely follows a linear trend implicating a resistivity value 0.35 Ωm.* ***Figure 2, top right:*** *CPE fibers were tested to observe the effects thermal drawing. The linear trend indicates the resistivity of CPE fiber to be 0.18 Ωm.* ***Figure 3, bottom left:*** *CPE channel fibers were tested under a range of flow rates. Different values for current were used to increase the initial resistance.* ***Figure 4, bottom right:*** *A linear region was isolated by using 1 mA and smaller range of flow rates. The channel fiber sensor was found to have a sensitivity of 5.237*10*^{5} *µV/µL/min.*

The channel fiber has comparable range but greater power consumption (76 mW) due to high current for increasing the initial resistance [6].

Future Work:

An automated setup for determining the response time. Verify the consistency of our results by testing fiber draws using the same preform design to explore the possibility customizing the resistivity of fibers. Vary the amount of layering of CPE or PC film insulation in the channel fiber to lessen the cooling rate and increase the resistance for a larger flow rate range. A proof of concept to demonstrate the easy integration the in fiber design professes.

Acknowledgements:

This project was sponsored by the National Nanotechnology Infrastructure Network Research Experience for Undergraduates Program and funded by the National Science Foundation under Grant No. ECCS-0335765. My thanks to my principal investigator, Dr. Zheng Wang, my mentor, Boxue Chen and my research group for their help and guidance; also to Dr. Marylene Palard and the University of Texas at Austin's Micro Electronic Research Center staff for their assistance.

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