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Research Experience for K-12 STEM Teachers : Charecterization of Electrospun Carbon Nanofibers (ECNF)

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Research Experience for K-12 STEM Teachers: Characterization of Electrospun Carbon Nanofibers (ECNF)

Abstract— There is a strong need for well-educated nano electronics device design engineers and therefore K-12 STEM teachers' training efforts are essential to meet future nanotechnology challenges. A group of three teachers are recruited through the NSF funded Research Experiences for Teachers. The group has investigated the characteristics of Electrospun Carbon Nanofibers (ECNFs) for bio-sensing applications. Nano-electronics have the potential to impact everything from computer processor to television displays to cell phones as well as have a major impact on the U.S. economy. So this research investigates the impact of the nano-electronics educational research on K-12 curriculum.

Introduction:

The research project is an exciting topic for teaching concepts of mathematics, science, and technology in middle and high schools. The teachers have learned about the engineering design and characterization concepts of carbon nanofiber (CNF) for biosensors applications through the active participation in the engineering research labs. Glucose biosensors have been shown to have increased effectiveness when their designs incorporate nanoparticles and nanostructures [1, 2]. Based on the research results the teachers develop lecture modules which they implement in their classes in the following school year.

Training and Professional Development:

Relevance of the research to K-12 Education: In this project the teachers have investigated and characterized CNF. The research problems, analytical method as well as the characterization procedure are related to math, science and physics courses. The research provides hands-on experience by participating in engineering-related project for middle and high school teachers. The team utilizes professional engineering software and hardware (such as Matlab, LEGO probe holder, oscilloscope, multi-meter) to develop their solutions and also generate presentations that convincingly demonstrate the value of their solutions. The skill provides with opportunities to apply the lessons of the classroom to the technical problems that are being faced in the workplace.

Design Challenges: The project provides the STEM teachers the opportunity to work on real world engineering challenges in a team environment. The backgrounds of the team members and or subjects they teach help them to work on this problem. The design problems are open-ended, where the goals are ill-structured, and there is no effective design plan specifying the sequence of actions to take in producing a design model. The results possess multiple solution methods, non-engineering success standards, non-engineering constraints, and collaborative activity systems, where the importance of experience and the use of multiple forms of representation are required (Jonassen, Strobel & Lee, 2006).

Methodology used to introduce the teachers to the research problem: The following methodology is used to introduce the teachers to the research problem:

- Weekly meeting with mentor
- Literature review
- Feedback from the program director during the weekly group meetings

The team follows the iterative design process which has the following steps:

1. Initial constrain and functional specifications
2. Design decisions based on the constrains and belief
3. Preliminary development of model
4. Result analysis
5. Satisfaction/dissatisfaction with the results
6. Remodeling
7. Final design

Engineering Research Activities:

A bienzymatic glucose biosensor that uses vertically aligned carbon nanofibers (VACNF) has been shown to detect glucose [2-4]. However, manufacturing VACNF is an expensive process. The goal of this research is to determine if non-aligned, thus less costly, electrospun carbon nanofibers (ECNF) incorporated as a part of a biosensor are also be able to detect glucose.

The objective of the research is to study the electrical characteristics of ECNF in various conditions (AC and DC). All five dry ECNF samples are found to be ohmic and exhibit linear behavior within the range -2.226 V to 2.992 V and the operating frequency is within the range of 13 Hz to 850 KHz. As the ECNF samples' length increase and their cross-sectional area remain constant, it is predicted that their resistance increases and thus lower their output current. Data beyond this range behaved in a nonlinear manner. In addition, this study shows that ECNF does allow glucose to be detected. Its lower cost makes it a more economical choice over vertically aligned carbon nanofibers (VACNFs).

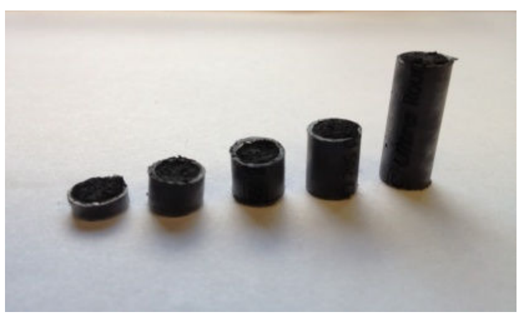

Figure 1: Dry ECNF samples – cylinders packed with ECNF, 0.25 cm to 2 cm

Methodology:

i. Resistivity measurement:

To find the resistivity of the dry ECNF, several cylindrical ECNF samples are created of various lengths (Figure 1). The cylinders are packed with dry ECNF using the same amount of force in order to get approximately the same density in each sample. Resistivity is determined for the ECNF samples using the relationship, $\rho = \frac{R}{L}(A)$; where, ρ is resistivity for the sample, R is the resistance of the ECNF sample, L is the length of the sample parallel to the current, and A is the cross sectional area through which the current passes through. Table 1 shows the measured resistance values and the specifications of the samples.

Table 1: Resistance of the ECNF samples

Length (cm) of cylinder	Volume of cylinder (cubic centimeters)	Mass of ECNF (g)	Density (g/cubic centimeters)	Resistance (ohms)
0.25	0.139	0.02	0.1×10^3	14
0.50	0.277	0.04	0.1×10^3	18
0.75	0.416	0.06	0.1×10^3	22
1.0	0.554	0.08	0.1×10^3	28
2.0	1.108	0.16	0.14×10^3	48

ii. DC Response :

It is observed that each CNF sample shows linear behavior within the range of -2.226V to 2.992V. As the length of the CNF samples increased and their cross-sectional area remained constant, it is expected that their resistance would increase and thus lower their current output. Data beyond this range behaved in a nonlinear manner and is therefore not included. The conductance of each sample is presented in Table 2.

Table 2: Measured Conductance

CNF sample size (cm)	Conductance (A/V)
0.25	0.04649
0.50	0.04393
0.75	0.03667
1.0	0.03507
2.0	0.02536

iii. AC Response:

An AC signal is applied to each sample. The voltage across each sample is measured and compared with the input signal. The ECNF voltage signal is in phase with the input signal within the range of 13 Hz to 850 KHz (Figure 2). Frequencies less than 13 Hz show non-linear behavior. The dry electrospun ECNF operates also at high frequency, but a phase shift is observed at high frequencies (Figure 3).

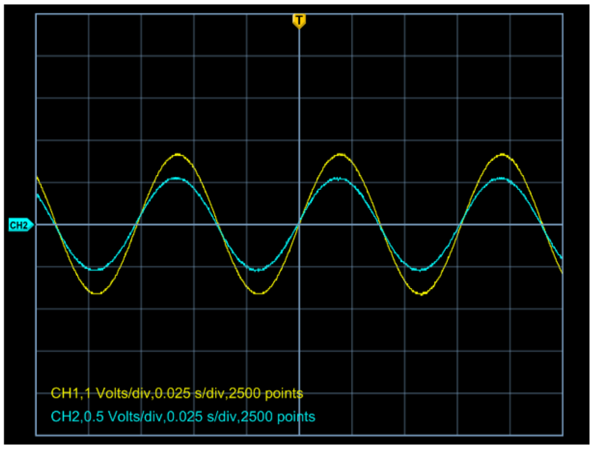

Figure 2: 2 cm long ECNF sample at 20 Hz

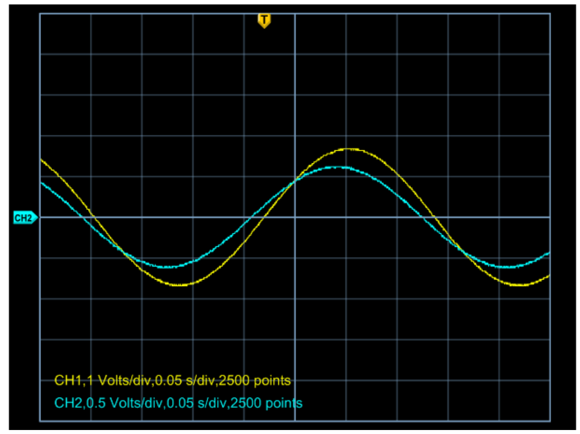

Figure 3: 2 cm long ECNF sample at 1 MHz

Conclusion/Future work:

Carbon nanofiber is one of the potential candidates for biosensors, specifically to detect glucose, and an important biosignatures to diagnose diabetes [5, 6]. The use of this type of biosensor in other medical applications such as in detecting other maladies would greatly benefit the general population. That's why the study of electrical characteristics of CNF palys an important role in STEM education. Through this participation the teachers have enhanced their knowledge in engineering and developed the skills to translate the research into their classroom practices, thus impacting their students and motivating them towards science, technology, and engineering disciplines.

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