INSTITUTO TECNONÓLOGICO Y DE ESTUDIOS SUPERIORES DE MONTERREY

MASTERS THESIS PROPOSAL

Fabrication of graphitic-carbon suspended nanowires through mechanoelectrospinning of photocrosslinkable polymers

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Supervising Committee

The committee members, hereby, recommend that the proposal by Antonio Osamu KATAGIRI Tanaka to be accepted to develop the thesis project as a partial requirement for the degree of Master of Science in Nanotechnology (MNT).

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List of Abbreviations

ITESM	**I**nstituto **T**ecnonólogico y de **E**studios **S**uperiores de **M**onterrey
CEM	**C**ampus **E**stado de **M**éxico
MNT	**M**aestría en **N**ano**t**ecnología *(Master of Science in Nanotechnology)*
CNWs	**C**arbon **N**ano-**w**ire**s**
EMS	**E**lectro**m**echanical **S**pinning
FFES	**F**ar **F**ield de **E**lectro**s**pinning
NFES	**N**ear **F**ield de **E**lectro**s**pinning
SU-8	a photoresist

INSTITUTO TECNONÓLOGICO Y DE ESTUDIOS SUPERIORES DE MONTERREY

Abstract

Faculty: Nanotechnology

School of Engineering and Sciences

Master of Science in Nanotechnology (MNT)

Fabrication of graphitic-carbon suspended nanowires through mechanoelectrospinning of photocrosslinkable polymers

by Antonio Osamu KATAGIRI Tanaka

Carbon nano-wires are versatile materials composed of carbon chains with a wide range of applications due to their unrivalled properties in electrical matters. Regardless of the high interest in the implementation of carbon nano-wires in several applications and devices, no feasible processes have been developed to fabricate carbon nano-wires. Carbon nano-wires have been fabricated with the use of a photoresist, but little is known about polymers that can produce more conductive carbon nanowires after pyrolysis. Various polymer solutions have been tested in near field electrospinning (NFES) and photopolymerization processes, however, few have been tested for nano-wire frabication purposes through pyrolysis. The intention behind the thesis proposal is to implement rheology analyses of different polymer solutions to determine if they can be easily electrospun at low voltages and then fabricate nano-wires with them. This thesis work arises from the need to test a greater variety of polymers with the goal to design a polymer solution to fabricate carbon nanowires with better properties than the current SU-8 polymeric nano-fibers. The research process will include the design of polymer solutions that can be electrospun, photopolymerized, and then pyrolyzed into conducting carbon nanowires. On the other hand, it is intended to engineer a newly designed polymer solution to achieve mass scale manufacturing of carbon nano-wires in a inexpensive, continuous, simple and reproducible manner.

keywords: nanotechnology, carbon, nano-wires, electrospinning, NFES

1 Introduction

[Chapter ready for review]

Carbon nano-materials are subjected to great interest for research purposes due to their various potential applications in diverse areas that take advantage of the nano-scale properties. [9] Carbon nano-materials are suitable for the catalysis, adsorption, carbon capture, energy and hydrogen storage, drug delivery, bio-sensing and cancer detection. [9] Due to some of matchless properties that allow carbon nano-materials to be utilized within multiple functionalities including high porosity, distinguished structures, uniform morphologies, high stability, high magnetic properties and high conductivity. [9]

This document bestow a thesis proposal to perform a research to engineer and design a polymer solution to achieve mass scale manufacturing of high conductive carbon nano-wires with a reduced diameter in an inexpensive, continuous, simple and reproducible manner. The research intends to involve several manufacturing processes such as near field electrospinning, photopolymerization, pyrolization and carbonization, as they have shown to be promising methods for the fabrication of carbon nano-materials. [2] See Figure 1.1. A number of processes have been developed for specific purposes of polymeric nano-fibers, some include surface deposition, composites, and chemical adjustments. Polymeric nano-fibers must be also pyrolyzed to generate carbon nano-wires with conductive capabilities [6] for electrochemical sensing and energy storage purposes.

Nanotechnology has explored different polymer patterning techniques to integrate carbon nano-wires structures. One technique is known as far-field electrospinning, a process in which electrified jets of polymer solution are dispensed to synthesize nano-fibers which then are pyrolyzed at high temperatures. One sub-technique derived from electrospinning is near field electromechanical spinning or EMS. EMS has proved to deliver high control in

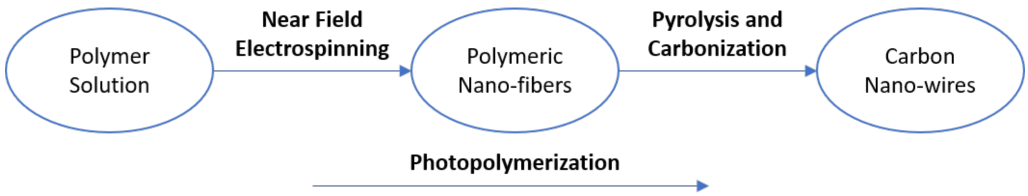


FIGURE 1.1: Fabrication process of carbon nano-wires to achieve through the proposed dissertation.

patterning polymeric nano-fibers. [2]

The proposal is to continue the previous work done in regards of the synthesis of carbon nano-wires. Previous work includes the fabrication of suspended carbon nano-wires by two methods: electro-mechanical spinning and multiple-photon polymerization with a photoresist. [2] This research proposal is intended to focus on electro-mechanical spinning processes only, to bring off polymer solutions that can be electrospun by near field electrospinning (NFES), photopolymerized and pyrolyzed into conducting carbon nano-wires. The polymer solutions described in [2] are to be amended to achieve the goal mentioned in the previous statement.

Near-field electrospinning or NFES allows large scale manufacturability combined with controlled guidance. [6] However, the reported efforts required the use of electric fields in excess of 200 kV/m for continuous operation, resulting in limited control for nano-fiber patterning in traditional NFES processes. [6] the current state-of-the-art synthesis processes for polymer nanofibers lack to yield precise, inexpensive, fast, and continuous manufacturing properties.

2 Problem Definition and Motivation

[Chapter ready for review]

Carbon nanowires have been fabricated with a photoresist by multiple-photon polymerization techniques. However little is known about polymers that can produce conductive carbon nano-wires after pyrolysis. The problem relays on the fact that it had been known that most polymers are non-graphitic [4]. In the past years photon polymerization processes have been applied to the fabrication of nano-structures with the use of a photoresist. [1] Photon polymerization techniques deliver patterning resolutions with nano-scale tolerances for the production of highly detailed structures, [5] However, it is typical of photon polymerization processes to yield small objects with waste resins that are often toxic. [8]

On the other hand, electrospinning has been acknowledged for as a process with promising results at nano-structure fabrication [1], yet there is little research regarding the implementation of electrospinning for the fabrication of carbon nano-wires. Electrospinning has the potential to be a more straightforward process for the design and fabrication of nano-structures, as it can achieve mass scale manufacturing in a continuous, simple and reproducible manner. [2] shows that electrospinning can be implemented with ease for carbon nano-wire synthesis. Mechano-electrospinning, a new variant of electrospinning shows promising results in the production of ordered carbon nano-wires. As stated in [2], mechano-electrispinning is an early technology invention, and brings new challenges, such as the reproducibility of carbon nano-wire production.

Since electrospinning seems to be a better alternative for carbon nano-wire synthesis processes; and for that purpose of its implementation, it is required to develop polymer solutions that can be mechano-electrospun, photopolymerized and pyrolyzed into conducting carbon nano-wires. Carbon nanomaterials have been subjected to research due to their various potential applications in diverse areas that take advantage of the nano-scale properties. [9] Carbon nano-materials are suitable for the catalysis, adsorption, carbon capture, energy and hydrogen storage, drug delivery, bio-sensing and cancer detection. [9] However most application are not currently feasible due to the lack of a continuous, simple and reproducible fabrication method. With the newly designed polymer solution, it would be possible to produce carbon nano-wires in large quantities, and therefore more applications will become feasible.

3 Hypothesis and Research Questions

[Chapter ready for review]

3.1 Research Hypothesis

The rheological properties of polymer solutions along with synthesis parameters (stage velocity, voltage, dispense rate) can be amended to obtain a low voltage electrospun-able, photopolymerizable and graphitizable fibers for the synthesis of carbon nano-wires with specified dimensions (diameter and length).

3.2 Research Questions

- Are there any evidence of carbon nano-wire fabrication though electrospun-able and pyrozable polymer solutions?
- What are the process parameters to consider/control for the fabrication processes of carbon nano-wires?
- What rheological properties are to be controlled/tested to deliver a electrospun-able and pyrozable polymer solution?
- Are there any efforts employed to the design of polymer solutions that can be electrospun, photopolymerized, and pyrolyzed into conducting carbon nanowires?
- Are the fabrication parameters defined in [2] optimal for the synthesis of carbon nano-wires through near-field electromechanical spinning?

4 Objectives

[Chapter ready for review]

4.1 General objective

Exercise the practice and feasibility of a new synthesis process to achieve mass scale manufacturing of carbon nano-wires in an inexpensive, continuous, simple and reproducible manner.

4.2 Particular objectives

- Design polymer solutions that can be electrospun by NFES, photopolymerized, and then pyrolyzed.

- Through rheological analyses, determine if polymer solutions can be easily employed for conducting carbon nano-wire synthesis.

- Determine and control the polymer solution rheological properties along with the process parameters of carbon nano-wire synthesis.

5 Theoretical Framework

[Chapter under work]

5.1 Electro-Mechanical Spinning

Diverse polymer patterning techniques have been developed to integrate and synthesize carbon nano-wires. A typical technique is electrospinning. Electrospinning requires the application of an electrostatic force to a polymer solution to spin fibers. The applied electric field, the solution conductivity, jet length, solution viscosity surrounding gas, flow rate and the collector geometry are important parameters that influence the fiber formation during the spinning. [7] Two sub-techniques can be derived from electrospinning depending on the distance between the dispensing electrode and the collector. The process in which the electrospun jet can be controlled near the tip is called NFES or near-field electrospinning. [3] Moreover, if the distance between the collector and the dispensing needle is farther, the configuration is known as FFES or far-field electrospinning. [7]

5.2 Carbon nano-fibers

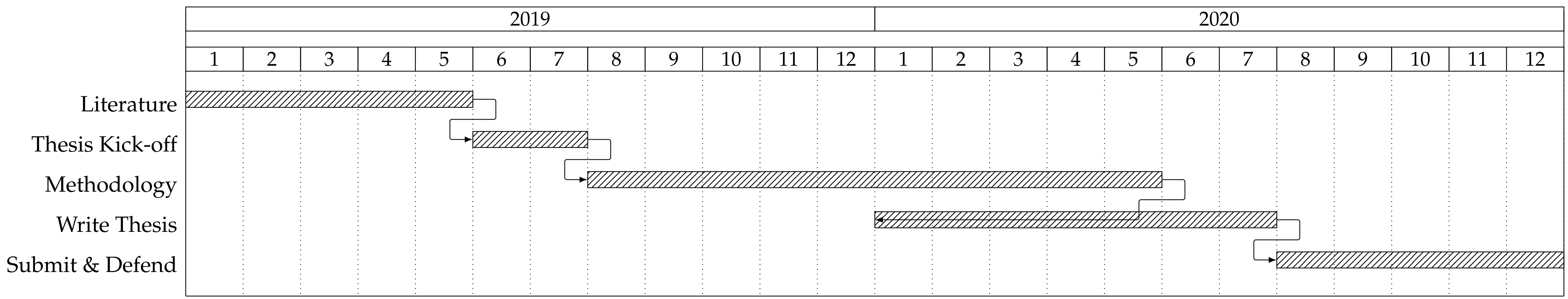
Carbon nano-wires (CMWs) are known as long, thin strings with diameters between 10 and 1 thousand nm; composed mostly by carbon atoms aligned parallel to the long axis of the fiber. [7] Carbon nano-wires are different from carbon tubes, as CMWs are not composed by graphene sheets in cylindrical form. [7]

6 Methodology

[Chapter under work]

7 Work Plan

[Chapter under work]



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