

FY 2008 Project Proposal

Project No. ELMO-08

Analysis of the Nature of the Self-Assembly Phenomenon of Nano-fibers for tissue engineering and drug delivery

Project Team:

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Objective:

This proposed work focuses on the study of the Nature of the Self-Assembly Phenomenon of Nano-fibers for tissue engineering and drug delivery. It offers the possibility of using nanofibers to make new, specialized materials with organized patterns that can be used for such applications as wound dressings, filtrations and bioscaffolds.

Key objectives of this proposed work are: (1) production of controlled self assembly structures, (2) fabrication of nanofibers by electrospinning, and (3) evaluation of the potential uses of these highly ordered nanofibers. Backgrounds and specific proposed tasks associated with these objectives are discussed below.

State of the Art:

Nanotechnology is an emerging field which uses the principles of science and engineering to fabricate materials or structures of dimensions in the nanometer scale [1]. The great interest in nanoscale materials spur from the unusual and unique property profile these materials exhibit compared to macromaterials. Novel physical, chemical and biological properties such as unique shape, orientation, surface chemistry, topology and reactivity exhibited by these materials originate from their small dimensions. These material properties translate into unusual electrical, optical, magnetic, mechanical, thermal and biological properties for these materials. Some of the nanostructures or nanoscale materials currently under investigation include quantum dots and wires, nanoscale self- assemblies and thin films, nanocrystals, nanotubes, nanowires, nanorods, nanofoams, nanospheres and nanofibers. Some of the next frontier areas that will benefit from these nano scale materials include nano electronics [2], nano electromechanical devices [2] and nano optical devices [3]. Among the nanostructures discussed above, nanofibers form one of the most extensively investigated areas recently [4].

The architecture of non woven nanofiber matrices, due to their structural similarity to natural extracellular matrix, could present an ideal substrate on which cells can adhere, proliferate and organize into tissue. Further, the high surface area to volume ratio of the fibers can lead to high rates of delivery of drugs or bioactive molecules from these matrices making them potential candidates for developing controlled drug delivery systems.

Literature shows that polymeric nanofibers can be fabricated using various processing techniques such as drawing [4,5], self assembly [4,6], template synthesis [4,7], phase separation [4,8] and electrospinning [4]. Among these, electrospinning is the most general and simplest technique that can be used to fabricate polymeric nanofibers.

This proposed work focuses on the study of self assembled polymeric nanofibers. It offers the possibility of using nanofibers to make new, specialized materials with organized patterns that can be used for such applications as wound dressings, filtrations and bioscaffolds.

Approach:

1-Production of controlled self assembly structures

Molecular self-assembly is a strategy for nanofabrication that involves designing molecules and super molecular entities so that propensity to shape complement causes them to aggregate into desired structures [8]. Self-assembly exhibits many advantages as a strategy, as it carries out many of the most difficult steps in nanofabrication particularly the ones involving atomic-level modification of structure using very highly developed techniques of synthetic chemistry. It also draws from the enormous wealth of examples in biology for inspiration. Indeed, it is considered as one of the most important strategies used in biology for the development of complex functional structures. Furthermore, since molecular self-assembly requires that the target structures be the thermodynamically most stable ones open to the system, it tends to produce structures that are relatively defect-free and self-healing. Despite the realization of the outstanding merits of self-assembly, the concept still poses many intellectual challenges that have been dealt with over the years.

In light of the above introduction, and in the direction of producing and controlling self assembly structure, block copolymers or segmented polymeric are interesting because they can microphase separate and organize to form periodic nanostructures. Figure 1 shows the experimental phase diagram of polyisoprene-block-polystyrene diblock copolymers. Five different ordered structures have been observed for this system [9].

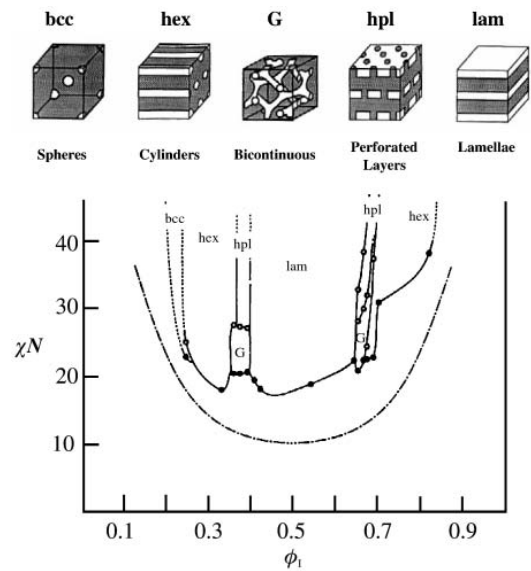


Figure 1 - Experimental phase diagram (interaction parameter vs. composition) for low molar mass PS-PI block copolymers, the closed circles represent order-disorder transitions (ODT) and the open circles order-order-transitions (OOT). The ODT and OOTs were determined by rheology and the structures by a combination of TEM, SANS and SAXS.[9]

Because the blocks are covalently bonded to each other, they cannot demix macroscopically. In "microphase separation" the blocks form nanometer sized structures. Polymer scientists use thermodynamics to describe how the different blocks interact. The interaction parameter, gives an indication of how different, chemically, the two blocks are and whether or not they will microphase separate. Depending on the relative lengths of each block, several morphologies can be obtained. Sufficiently different block lengths lead to nanometer-sized spheres of one block in a matrix of the second (for example PMMA and PS). By using less different block lengths, a cylinder geometry can be

obtained. Blocks of similar length form stripes (often called lamellae in the technical literature). The nanoscale structures created from block copolymers could potentially be used for creating devices for use in nanoscale-templating and nanoscale separations.

Task 1 – In the course of this proposed work, we are planning to study two potential system that present self assembly behavior

- Blends of segmented polyurethane with different hard block and molecular weight synthesized by Dr. Auad's group
- Poly(ethylene oxide)-co-Poly(lactic acid) block copolymers that will be synthesized during this proposal (Dr Auad and Dr. Broughton's groups)

Different techniques will be used in order to understand the phase separation effect and the organization/assembly of the final structures (e.g. Atomic Force Microscopy, Light Scattering and Optical Microscopy). A chaotic advection blender will be used to prepare immiscible blends with controlled structures [10].

Task 2- Dr. Elmogahzy's team will carry out the analysis associated with blending segmented polyurethane with different hard block and molecular weight synthesized by Dr. Auad's group. Different modes and outcomes of the blending process will be investigated for the purpose of modeling of the blending phenomenon. The models developed will assist in evaluating the goodness of blend. Two categories of models will be developed: exploratory models to describe and characterize the self-assembly phenomenon, and statistical models describing the various patterns associated with blending.

(2) Fabrication of nanofibers by electrospinning

The standard setup for electrospinning consists of a spinneret with a metallic needle, a syringe pump, a high-voltage power supply, and a grounded collector. The polymer solution is loaded into the syringe and this liquid is driven to the needle tip by a syringe pump, forming a droplet at the tip. When a voltage is applied to the needle, the droplet is first stretched into a structure called the Taylor cone. If the viscosity of the material is sufficiently low, the droplets are electro-sprayed and an electrified liquid jet is formed. The jet is then elongated and whipped continuously by electrostatic repulsion until it is deposited on the grounded collector. Whipping due to a bending instability in the electrified jet and concomitant evaporation of solvent allow this jet to be stretched to nanometer-scale diameters. The elongation by bending instability results in the fabrication of uniform fibers with nanometer-scale diameters (approximately 100-400nm). An example of one experimental set up used for electrospinning is shown in Figure 2

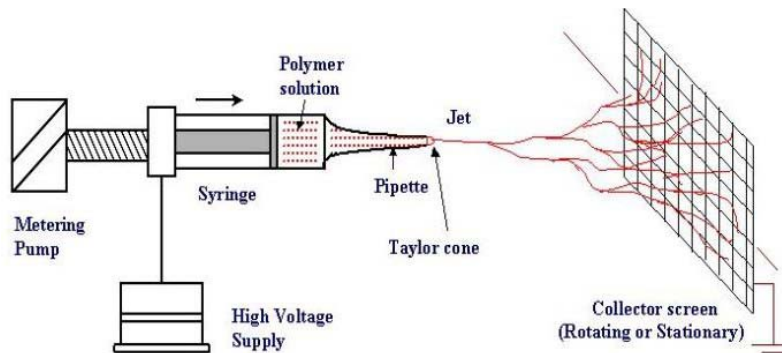


Figure 2 – Schematic of a electrospinning set up.

Task 3: In relation to electrospinning, the specific task that will be handled in this proposed work is the production of different sizes and controlled aligned nano-fibers showing self assemblies structures by electrospinning method. In this regard, we will use the concepts learned during the development of objective 1 in order to obtain ordered structures (fibers). Size, constitute, thickness and surface structure of the obtained multilayered fibers will be tailored according to the requirements. (Dr Auad and Dr. Broughton)

Task 4:Dr. Elmogazy and Dr. Farag will evaluate the structural and physical characteristics of the fibers. Images obtained from scanning electron microscope (SEM) and Transmission Electrical Microscope (TEM) will be studied for the effect of the polymer concentration and electric field on fiber diameter and its distribution. Using the models discussed earlier along with the structural observations and the physical values, more precise exploratory and predictive models will be developed.

(3) Evaluation of the potential uses of highly ordered nanofibers

As discussed earlier, the architecture of non woven nanofiber matrices, due to their structural similarity to natural extracellular matrix could present an ideal substrate on which cells can adhere, proliferate and organize into tissue. Further, the high surface area to volume ratio of the fibers can lead to high rates of delivery of drugs or bioactive molecules from these matrices making them potential candidates for developing controlled drug delivery systems. During this objective we will study possible applications of these systems.

The initial results of this work will be used to develop a more comprehensive study of the problem and will provide initial data that will be used to generate an extramural funding proposal that will be submitted to an agency (NSF, NIH, DOE, etc.).

Dr Elmogazy, Dr Auad and Dr. Broughton will be in charge of this task.

New Resources Required:

We expect to spend part of the money of this proposal in a microscope hot stage, a chotic blender, a dynamic light scattering and a FTIR microscope (The last two equipment will be purchased in a share base).

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BIOGRAPHY SECTION

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Co-author of the Book "Fiber To Yarn Manufacturing Technology" with Mr. Charles Chewning, Jr. (Vice President of Cotton Incorporated). Published by Cotton Incorporated, U.S.A. (cottoninc.com), 2001

Author of the New Book "Fiber-to-Fabric Engineering" Published by Woodhead-Publishing Co. UK- Out for distribution May 2008.

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Publications: (from among more than 25)

- 1-“Characterization of nanocellulose reinforced shape memory polyurethanes”, M L Auad, VS Contos, S Nutt, M I Aranguren, NE Marcovich, *Polym Int* **57**:651–659 (2008)
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January, 1970 - September, 1976: Senior Research Chemist, Polyester Research and Development Division, The Goodyear Tire and Rubber Company, Akron, Ohio

c. Publications (from among more than 50)

1-Jaewoong Lee, Xuehong Ren, R. M. Broughton, Jie Liang, S. D. Worley, and T. S. Huang, Electro-spun Antimicrobial Acrylic Fiber, *Journal of the Korean Society of Dyers and Finishers* **19**, (2) 44-49 (2007)

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c. Publications

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