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Influence Of A Magnetic Field In The Electrospinning Of Nanofibers Containing Fe_3O_4 Nanoparticles

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Abstract

This work investigates the effect of a magnetic field on the electrospinning of polymeric nanofibers containing magnetic nanoparticles (Iron Oxide nanopowder, Fe_3O_4, particle diameter of 20 nm to 30 nm). Polymeric solutions containing PVDF, DMF and acetone with a concentration of 18 wt % and DMF to acetone ratio of 3 to 1 were used. Nanopowder to PVDF ratios of 1:5, 1:10, and 1:15 were analyzed. During electrospinning, two Helmholtz coils were mounted on the system in order to create a uniform magnetic field. Different separations, angles and magnetic fields were applied to the nanofibers. The morphology of the nanofibers and solutions was analyzed by Fourier transform infrared spectroscopy (FTIR), and scanning electron microscopy (SEM). The addition of a magnetic field controlled the directionality of the polymer flow but the fibers were not well-oriented. The best DC voltage to improve results is yet to be determined.

Keywords: Electrospinning, Magnetic Field, Nanofibers

1. Introduction

Lately, magnetic nanostructures have gained a lot of attention due to their important properties which result in a large number of devices and applications in many research fields like Medicine and Electronics. These nanostructures are also potentially useful as active components for ultrahigh-density data storage, as well as in the fabrication of sensors and spintronic devices. In addition, they show distinguishing properties compared to bulk materials.

PVDF, (poly vinylidene fluoride) is a polymer frequently used in the fabrication of nanofibers due to its excellent chemical stability, mechanical properties, and ferroelectricity. By combining a solution of PDVF and different solvents as DMF and Acetone in the electrospinning process, we can produce polymer fibers ranging from nanometers to micrometers. The paramagnetic properties of iron oxide nanopowder (Fe_3O_4) is the main topic of the studies presented in the literature; as well as its potential applications, such as magnetic storage devices, catalysis, and sensors. Fe_3O_4 can be found in the market with diameters between about 1 and 100 nm with purity above 95%.

The main objective of the current research is to find the electrospinning assisted by magnetic field parameters and obtain the magnetic response in our nanofibers. We also have as objectives investigating the possibility of achieving the thinnest diameter in the fibers and attempting to control the position of the fiber with the field.

2. Experimental Methods

2.1 Materials

PVDF with a density of 1770 kg/m^3 by Sigma-Aldrich and Iron Oxide Nanopowder (Fe_3O_4, particle diameter of 20 nm to 30 nm) by US Research Nanomaterials Inc. were used as solute. For solvents N,N-dimethylformamide (DMF) with a density of 944 Kg/m^3 and Acetone with a density of 791 Kg/m^3, both manufactured by Sigma-Aldrich were used. All polymeric solutions in this study that contain PVDF, DMF and acetone have a concentration of 18 wt % and the ration from DMF to Acetone is 3 to 1. The main reason why this solution should be adopted is, because it has better viscosity to obtain thinner nanofibers in the electrospinning process. From these samples the ratio of quantity of nanopowder to PVDF was varied from 1:5, 1:10 and 1:15. This mix of solutions was achieved at a temperature of 55^{o}C after stirring overnight.

2.2 Magnetic Electrospinning

Magnetic Field was applied during the electrospinning *in situ*. A pair of Helmholtz Coils, each having 200 turns, and carrying a current which varied between 0.5 to 3 Amperes, separated with a distance equivalent to the radius of the circular loops which are 10.5 cm were used. They produce a homogeneous magnetic field B in the mid-plane between the two circular coils, given by:

$$B = \frac{N\mu_o I}{2R} \tag{1.1}$$

where B is the Magnetic Field, μ_o is the permeability constant, I the current in Amperes and R is the radius of the circular coils. A high voltage power supply (ES30, 0-30KV) was used at 15KV to create an electric field.

In order to obtain oriented nanofibers deposited on a silicon wafer, a DC step motor with a speed controller was setup to rotate the sample in the middle of the electric field. The DC motor was connected to a 2 cm plastic cylinder with the silicon wafer attached. The speed of rotation during the synthesis was around one revolution per second. The distance between the needle and the metal collector was 10 cm and the syringe used was a ½ cc Becton Dickinson with a needle diameter of 0.40 mm and with length of 13 mm.

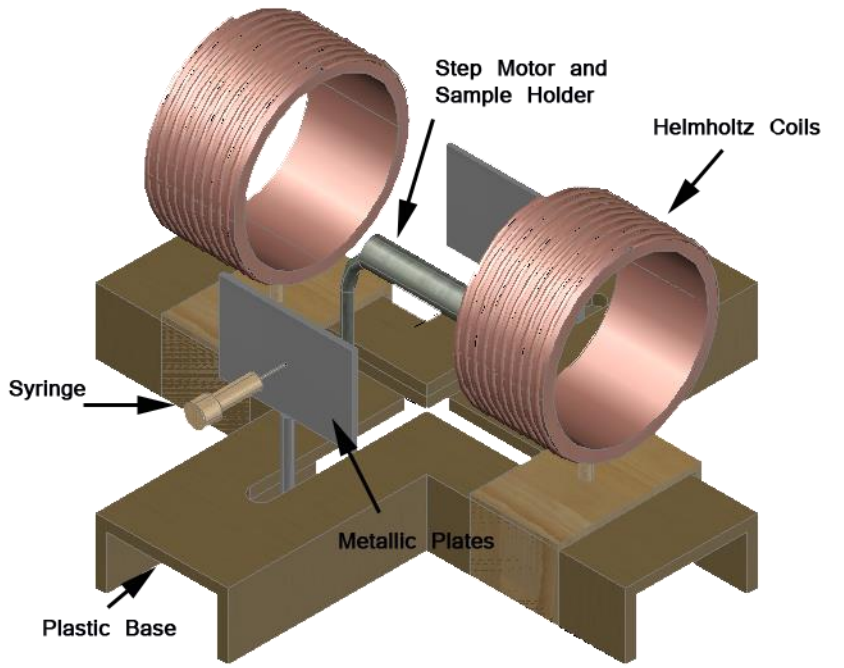


Figure 1. Experimental Setup for the Magnetic Electrospinning

Table 1. Magnetic Field and Current Relation on the Experiments

Current in Amperes	***Magnetic Field Applied in Gauss***
1.000	11.96
1.500	12.57
2.000	23.94
3.000	35.90

In order to measure the response of the nanofibers with higher magnetic fields, an axial cylindrical neodymium magnet of 6500 gauss was used. This magnetic field was applied to the samples in the optical microscope to observe the response.

2.3 Characterizations

Nanofibers morphology was observed by using a scanning electron microscope manufactured by JEOL model 6480LV at 5KV with magnification of 10,000. The size of the fibers and agglomerates of Iron oxide diameters and spheres was determined by the software "*image J*" developed by the National Institute of Health.

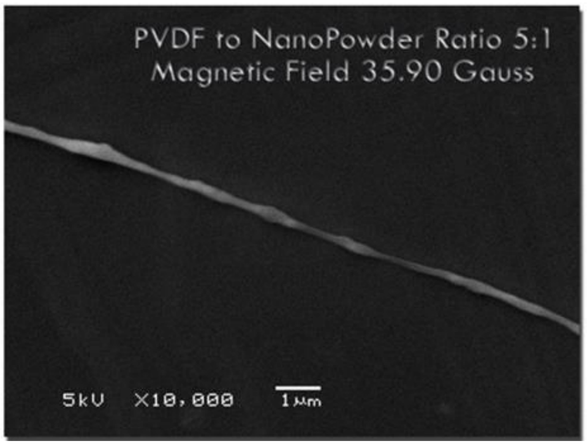
3. Results and Discussions

By observing the electrospinning process, it can be seen that with the application of the electromagnetic field during fiber deposition, the polymer flow results more oriented towards the silicon sample. This means that it is easier to collect nanofibers on the silicon substrate using electrospinning assisted by magnetic field.

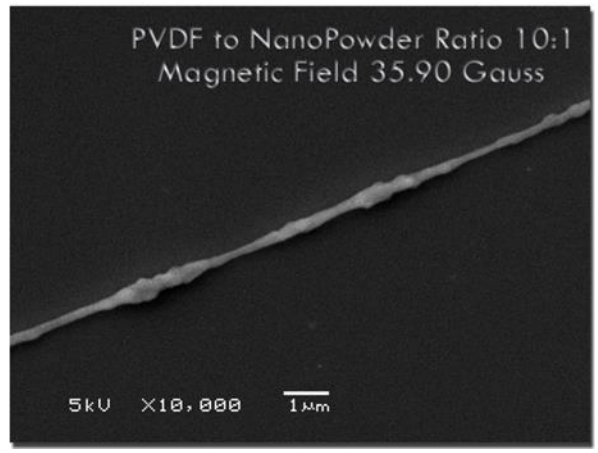
Figure 2 shows typical nanofibers obtained with different PVDF to nanopowder ratios. It is evident that the nanoparticles form agglomerates that are distributed along the fibers. The diameters of the nanofibers resulted in the range between 100 nm and 700 nm. No correlation between the concentration of nanoparticles and diameter was observed.

Figure 3 compares fibers formed with and without the application of the electromagnetic field. It is observable that the presence of the electromagnetic field leads to smoother fibers. This is most likely related to the fact that the nanoparticles get better embedded in the fiber when magnetized. Furthermore no significant difference was observed when varying the intensity of the magnetic field.

Finally, we can observe in Figure 4 a response of the nanofibers with higher magnetic fields, in this case an axial cylindrical neodymium magnet of 6500 gauss. Figure 4a shows a *100x* magnified nanofiber without magnetic field. Figure 4b shows the same nanofiber after applying the magnetic field.



(a)



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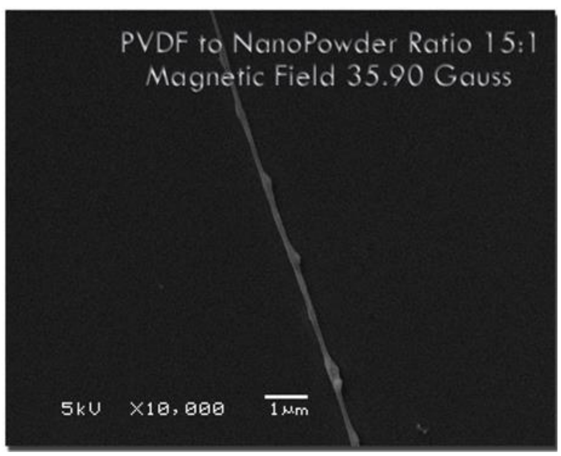
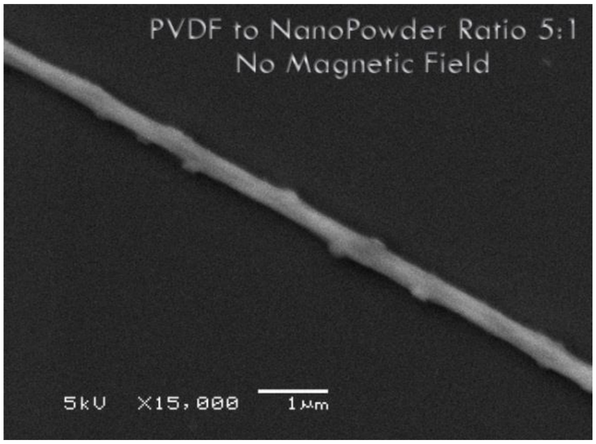
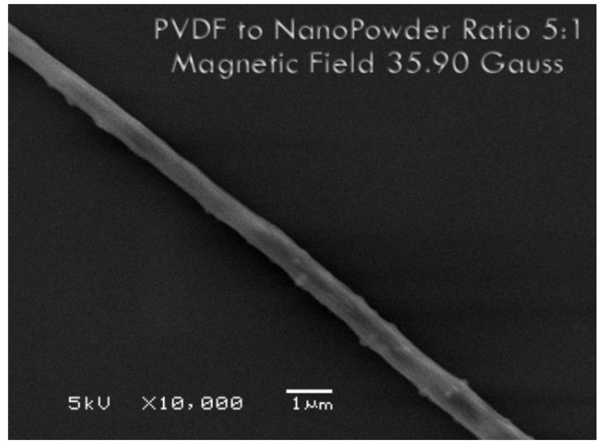


(c)

Figure 2. Micrographs of samples processed from polymeric solutions containing PVDF with a concentration of 18 wt % dissolved in DMF to Acetone ratio of 3 to 1, and with nanopowder to PVDF ratios of: (a) 1:5, (b) 1:10, and (c) 1:15.



(a)



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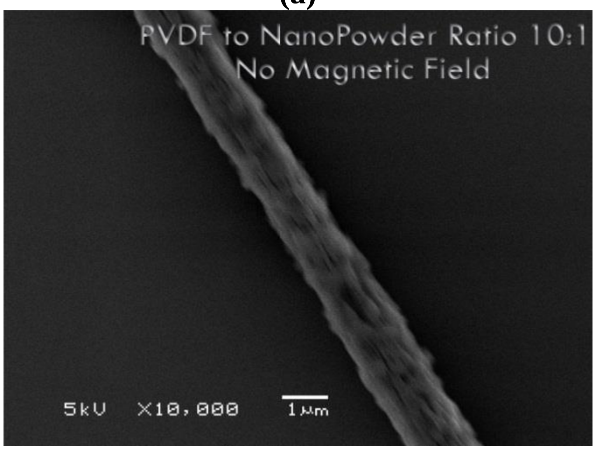

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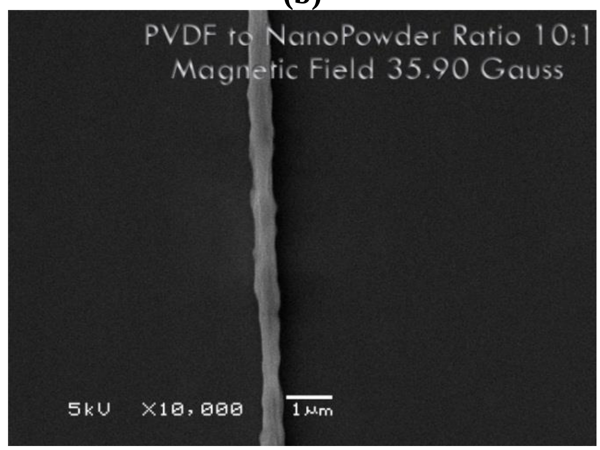

(d)

Figure 3. Micrographs of samples processed from polymeric solutions containing PVDF with a concentration of 18 wt % dissolved in DMF to Acetone ratio of 3 to 1. Nanopowder to PVDF ratio of 1:5: (a) without electromagnetic field, and (b) with electromagnetic field. Nanopowder to PVDF ratio of 1:10: (c) without electromagnetic field, and (d) with electromagnetic field.

(a)

(b)

Figure 4. Optical images of samples processed from polymeric solutions containing PVDF with a concentration of 18 wt % dissolved in DMF to Acetone ratio of 3 to 1. Nanopowder to PVDF ratio of 1:5: (a) without electromagnetic field, and (b) after magnetic field of 6500 Gauss was applied.

4. Conclusions

The application of the electromagnetic field during fiber deposition resulted in better orientation of the polymer flow towards the silicon substrate and in future work it will be easier collecting nanofibers right on target. The presence of the uniform electromagnetic field leads to smoother fibers with diameters in the range of 100 to 700 nm that exhibit magnetism at room temperature. Fe_3O_4 agglomerates were distributed in all the samples of this study.

We clearly observed a magnetic field response of the nanofibers with higher magnetic fields. By getting Helmholtz Coils with more turns and a more powerful power supply it seems that will be possible to have a better control of the deposition process.

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6. References

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