

## MATERIAL BASED ON NANOFIBER FOR ARTIFICIAL MUSCLE

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**Abstract.** Artificial muscles are likely to be essential components of robotics, and a variety of micro-machinery. The artificial muscles, have the potential to allow future robots to operate with superior muscle elasticity and isometric stress generation, even at extreme temperatures. Some new nanofibers for an artificial muscle is presented in this paper. The artificial muscle is based on a contractile polymer gel which undergoes abrupt volume changes in response to variations in external conditions. The tubes and wetting surfaces of the valves are constructed from teflon which is chemically inert and the fibers are made from Poly-Vinyl Alcohol PVA, alone or with PMMA and as magnetic polymer, with magnetite.

**Keywords:** nanotechnologies, nanorobotics, carbon nanotubes, artificial muscle.

### 1. INTRODUCTION

Nanotechnology is an emerging technology seeking to exploit distinct technological advances controlling the structure of materials at a reduced dimensional scale approaching individual molecules and their aggregates or supramolecular structures.

The resultant materials have been demonstrated to have enhanced properties and applicability; and these materials are expected to be enabling technologies in the successful development and application of nanomedicine.

Nano-medicine is defined as the monitoring, repair, construction, and control of human biological systems at the molecular level using engineered nanodevices and nanostructures [1].

A natural muscle is a *contractile* organ, which consists of fibers which “actuate” force and motion in response to nervous stimulation.

Muscles contract by the chemo-mechanical action of the proteins actins and myosin, Figure 1.

Joints of the body are arrayed such that they comprise muscles which opposite and use each other.

Until present, only electrical/pneumatic servos are known, as follows:

Skeletal – voluntary and striated

Cardiac – involuntary, striated, and branched

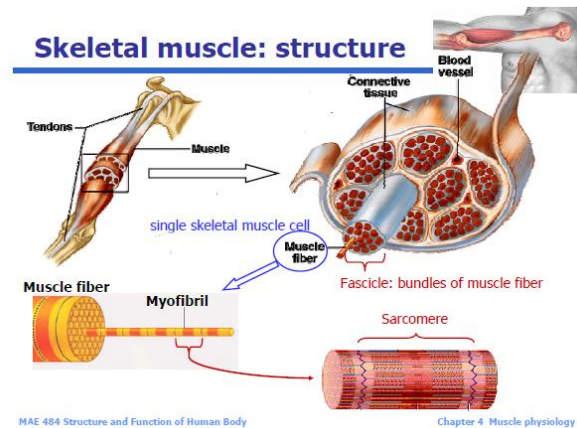
Smooth – involuntary and unstriated.

The functions of Biological Muscles consist in generate force, consumption of force, transmission of force and storage of energy. Muscles are attached to the bones with tendons, Figure 2.

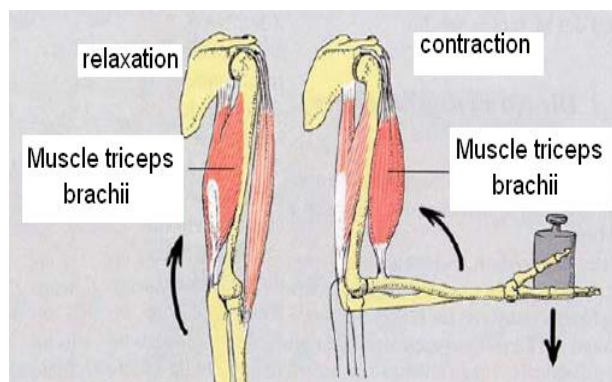
Types of the materials known for artificial muscles, that are very well known:

- Shape Memory Substances
- Shape Memory Alloys –SMA
- Shape Memory Ceramics
- Shape Memory Polymers
- Rheological Fluids

- Electro-Rheological Fluids –ERF
- Magneto-Rheological Fluids –MRF
- Magnetostrictive Materials
- Electrostrictive Materials
- Electrostatic Materials



**Fig. 1. The structure of natural muscle**



**Fig. 2. The structure of natural muscle**

The history of artificial muscles are not so actual, knowing that in 1619, Descartes postulated that sensory impulses activated muscle (reflection), and in 1780 - Galvani noticed frog muscles would contract with electrical apparatus.

Only in 1968 have been reported the first rubber artificial muscle. The most known artificial muscle is McKibbin muscle actuators, which consists in inflatable air tubes, delivering large force at a low frequency [2].

Polyacrylonitrile (PAN) is one of the most used polymer for the artificial muscle. Because it represent a combination of gel and plastic, it contracts under pH changes, support a contraction occur in 20 ms to a -20% strain and is very similar to human muscle in speed, exceeds human muscle in max force per cm<sup>2</sup> (2x). Also, it can be surrounded by solutions in latex tubes [3].

## 2. EXPERIMENTAL

### 2.1. Materials

It has been used nanofibers 100..200nm PMMA (polimetilmetacrilat) + PAN (polyacrylonitril) + Fe<sub>3</sub>O<sub>4</sub>. The polymer solution containing the iron oxide precursor iron (III) was electrospun and thermally treated to produce electrically conducting, magnetic carbon nanofiber mats with hierarchical pore structures.

We fabricated magnetic nanofiber films by ultrasonication followed by the electrospinning process to combine them into a thin film. The magnetite (Fe<sub>3</sub>O<sub>4</sub>) nanoparticles with mean crystallite size of 6–8 nm were synthesized through ultrasonication and using polyvinyl pyrrolidone (PVP) as the protecting agent.

The PVP-coated Fe<sub>3</sub>O<sub>4</sub> nanoparticles were dispersed into PVP ethanol solution and then electrospun directly to make nanofiber films. The diameters of fibers range between 200–400 nm, and the film thickness is about 50 μm. The Fe<sub>3</sub>O<sub>4</sub> nanofiber films display a superparamagnetic behavior.

The morphology and material properties of the resulting multifunctional nanofiber mats including the surface area and the electric and magnetic properties were examined using various characterization techniques.

The microscopy images show that uniform fibers were produced with a fiber diameter of ~600 nm, and this uniform fiber morphology is maintained after graphitization with a fiber diameter of ~330 nm.

The optical and transmission electron microscopy experiments reveals the formation of pores with graphitic nanoparticles in the walls as well as the formation of magnetite nanoparticles distributed throughout the fibers.

### 2.2. Results and discussion

In the case of many organic polymers, however, the mechanical strength is not enough to withstand the stresses, and the hollow tubular structure collapses unless the structure is stabilized. An alternative consists of synthesizing a coaxial nano-fiber of the polymer of interest on the shell and a sacrificial polymer in the core; in this case, the core plays the role of a template.

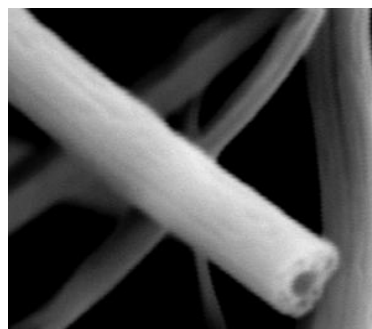
The whole structure may be stabilized and, if the properties of the template are appropriate, it may be degraded and eliminated without affecting the shell, leading to a hollow fiber made of the polymer of interest. Although it is a multi-step process, the basic coaxial fiber can easily be made in just one step.

Following this approach, we have fabricated hollow nanofibers of organic polymers like PAN and PMMA. PAN is a precursor of carbon fibers which has been electrospun.

This polymer, although very expensive, is broadly used in industry for this purpose, since its carbon yield is of about 40% to 50%. Very recently, co-electrospinning of PAN on the outside and of PMMA on the inside has resulted in the formation of coaxial fibers which, after a proper thermal treatment and carbonization, yielded hollow micron fibers of carbon.

The main difference is that, in our case, we used a different sacrificial polymer, poly (methylmetacrylate) (PMMA), which degrades at rather low temperatures (about 200 °C). After collecting the coaxial electrospun microfibers, the PMMA of both the shell and the core decomposes under the thermal treatment, so the tiny pores left in the shell by the PMMA are used by the PMMA in the core to escape, thus yielding a porous hollow fiber of stabilized PAN, which after carbonization became porous hollow carbon fibers.

The final fiber diameter is of the order of 0.9 microns, whereas the shell thickness is about 200 nanometers (figure 3).



**Fig. 3. SEM images of hollow nanofibers of stabilized PAN with PMMA**

Magnetic polymer composites represent a class of functional materials, where magnetic nanoparticles are embedded in polymer matrixes. There has recently been a considerable amount of interest in these polymer composites because they hold potential for applications in cell separation, medical diagnosis, high density information storage media, electromagnetic device and electromagnetic interference suppression [4].

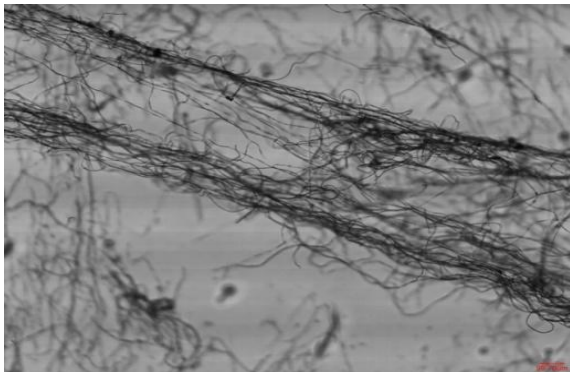
Usually, the magnetic polymer composites can be tailored to exhibit good filmforming and processing properties, besides electrical, magnetic and optical properties.

Recently, a considerable amount of interest in these magnetic polymer composites, such as Fe<sub>3</sub>O<sub>4</sub> /polyaniline [5], Fe<sub>3</sub>O<sub>4</sub> /poly (methylmethacrylate) [6], Fe<sub>3</sub>O<sub>4</sub> /poly (vinyl chloride) [7], Fe<sub>3</sub>O<sub>4</sub> /poly

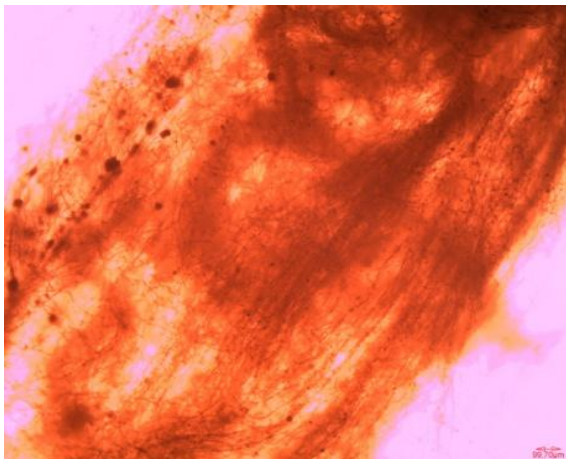
(acrylamide) [8],  $\gamma$ -Fe<sub>2</sub>O<sub>3</sub> /polyaniline [9],  $\gamma$ -Fe<sub>2</sub>O<sub>3</sub> /polyimide [10] and SnO<sub>2</sub> /polyaniline [11], has been attracted.

The deposition of magnetite on the polymer PVA-PMMA, have been achieved in our laboratory and the proof for its synthesis, was put into evidence as it could be seen in Figure 4, by optical microscopy.

Other spectral evidence for such materials will be report in our future publications.



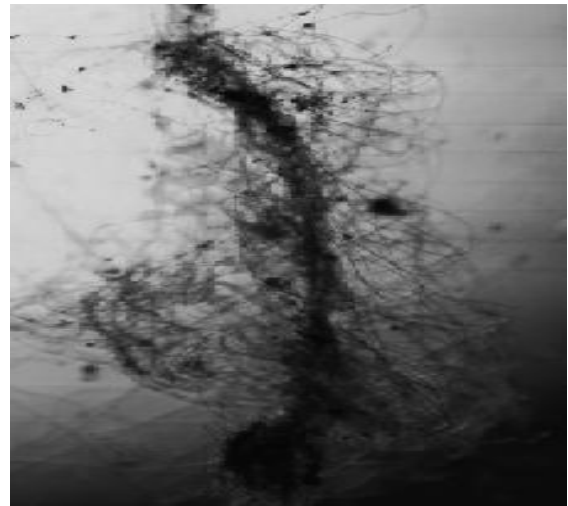
(a)



(b)



(c)



(d)

**Figure 4. The optical microscopy images of PVA-PMMA-Fe<sub>3</sub>O<sub>4</sub> nanofibers**

### 3. CONCLUSIONS:

The morphology and material properties of the resulting multifunctional nanofiber materials were examined using microscopical techniques.

The microscopy images show that uniform fibers were produced with a fiber diameter of ~600 nm, and this uniform fiber morphology is shown, too.

The optical and transmission electron microscopy experiments reveals the formation of pores with graphitic nanoparticles in the walls as well as the formation of magnetite nanoparticles distributed throughout the fibers.

### 4. REFERENCES

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