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Potential applications of nanofiber textile covered by carbon coatings

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Materials

ABSTRACT

Purpose: Nanospider technology is modified electrospinning method for production nanofiber textile from polymer solutions. This material can be used as wound dressing and filter materials for example. Carbon coatings deposited onto surface of polymer nanofiber textiles are predicted to improve filtration effectivity of filters and bioactivity of wound dressings. Carbon coatings have been produced by Microwave Radio Frequency Plasma Assisted Chemical Vapor Deposition (MW/RF PACVD) method.

Design/methodology/approach: Carbon coatings were deposited on polymer nanofiber textile by MW/RF PACVD method. Nanocomposite obtained in this way was characterized by the contact angle studies and by scanning electron microscope (SEM).

Findings: Carbon coatings can be deposited on the polymer nanofibers by MW/RF PACVD method. Content of diamond phase in produced carbon coatings has been confirmed by wetability test. A SEM microscopic images have shown that the spaces between the nanofibers have not been closed by the material of the film.

Research limitations/implications: MW/RF PACVD makes carbon coating synthesis possible in lower temperature, what is essential in case of applying the polymer substrate. Use of any other method than MW/RF PACVD for deposition of carbon coatings onto polymer nanofiber textile is not covered in this paper.

Practical implications: Nanofiber textile produced by Nanospider is very good mechanical filter. Carbon onto surface of nanofibers can cause from this material active filter. Since this nanocomposite enables the transport of oxygen and exudate, simultaneously is impenetrable for bacteria or even viruses, it can be used for wound dressing.

Originality/value: It is our belief that we are first to have deposited carbon coatings on nanofiber textile. We hope that in this way we have prepared very good material for filtration of air and for wound dressing.

Keywords: Nanomaterials; Carbon coatings; Nanofibers; Nanocomposites

1. Introduction

Currently, use of nanometric materials in all fields of our life is growing exponentially. This naturally brings new technological and scientific challenges, most of them are related to the protection of our health or sometimes life. Nanofibers have unique characteristics such as very large surface area-to-volume ratio and high porosity with very small pore size. Therefore nanofibers can be promising materials for many biomedical applications including the production of artificial blood vessels [1], scaffolds for engineered tissues [2], wound dressings [3], and filter [4].

Recently, the electrospinning has been recognized as an efficient method for the production of polymer nanofibers. Properties of this material are depended on parameters of electrospining, but in our opinion these properties can also be controlled by modification of surface of nanofibers. Possibility of modification of surface polyacrylonitrile based carbon fibers by plasma assisted method has been proved [5]. This modification can plays very important role in biomedical applications. In this case, area of our interests is focused on covering polymer nanofiber textile by carbon coatings.

Carbon coatings have emerged as a potential material, for medical applications, in recent years due to its high hardness, low frictional coefficient, high wear and corrosion resistance, chemical inertness. All these properties, together with biocompatibility, match well with the criteria of a good biomaterial for applications in orthopedic [6] and dentistry [7] or cardiovascular [8]. It has been proved that carbon coatings guarantees high wear [9] and corrosion [10] resistance.

Carbon coatings can be produced by various methods, Microwave/Radio Frequency Plasma Assisted Chemical Vapour Deposition (MW/RF PACVD) method seems to be suitable for deposition these coatings on polymer substrates. This method makes possible to produce thin coatings at very low temperature, lower than temeperature of melting of most polymers.

Polymeric materials covered by carbon coatings are also widely used in biomedical fields [11,12]. High biological activity of carbon, particularly Diamond Powder Particle (DPP) has been proved [13]; DPP has a very high biological activity in living organism at a molecular level. In this case the mechanism of inhibition of oxidative stress by DPP in vitro was established.

This fact has persuaded the authors of this paper to utilize deposition of carbon coatings on nanofiber textile, in our opinion such prepared nanocomposite can be used as material for wound dressing or filter. Moreover, it has to be underlined that it is our belief that we are first to have deposited carbon coatings on nanofiber textile.

2. Experimental

2.1. MW/RF PACVD method

Carbon coatings have been produced at the Institute of Materials Science and Engineering, Technical University of Lodz (Poland), by Microwave Radio Frequency Plasma Assisted Chemical Vapor Deposition (MW/RF PA CVD) method [14]. The apparatus for carbon film synthesis by this method is presented in Figure 1. In this system plasma is initiated by two source of energy working at microwave frequency and radio frequency. In this method it is possible to apply one or both frequencies simultaneously, or to excite of plasma by use MW or RF separately.

Microwave energy is transferred from the generator to the chamber by circulator, tuner and quartz tubing. The RF energy is supplied to the system through an isolated electrode. The system is additionally equipped with vacuum pumping, gas dosing and control modules. For the synthesis of carbon films pure methane has been used. Pure methane, as a source of carbon, was supplied through a shower device in the vicinity of the sample.

During the film deposition the main parameters were as follows: flow rate of gase 20-60cm^3/min, RF power 150-300 W, negative self-bias voltage 100-600 V, MW power 100-1000 W.

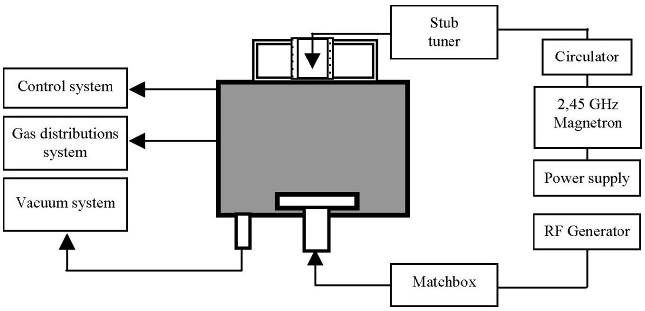

Fig. 1. Schematic of deposition system used in presented work

The substrates were placed on the substrate holder inside the deposition chamber by pumping down to several Pa. Depositions were carried out for various lengths of time: 10 - 30 min. Carbon coatings have been plotted on the nanofiber textile produced from the poly (vinylalcohol) (PVA) and polyurethane (PUR), formed onto basic fiberous material – polypropylene (PP).

2.2. The Nanospider technology

Nanofiber textile has been used as the substrate produced by the modern Nanospider method. This technology was elaborated at The Technical University of Liberec (Czech Republic), within The Department of Nonwovens, and has already been patented. This commercial methods for production of polymeric nanofibres is used in industrial range and was documented by Jirsak [15].

Nanospider is a modified electrospinning method. This is a simple and versatile method for production ultra-thin fibers from a variety of materials that include polymers. This technique requires the use of a high voltage electrostatic field to create an electrically charged stream of polymer solution or melt. In a typical process, high voltage is used between a grounded collector and a capillary tube. A droplet of a liquid polymer is brought to the tip of a capillary and upon voltage application the droplet forms a Taylor-cone. When the applied electric field overcomes the surface tension of the droplet, a charged jet of liquid is ejected from the tip of cone. During the jet's travel, the solvent gradually evaporates, and a charged polymer fiber is left to accumulate on the grounded target.

The innovatory idea of the Nanospider is based on the possibility of producing nanofibers from a thin layer of liquid polymer. In this case Taylor cones (the source of nanofibers) are created on the surface of a rotating roller, immersed in a polymer solution.

Because the Taylor streams are formed next to each other, throughout the entire length of the roller, this revolutionary idea produced many advantages, such how high productive ability. Nanospider has the ability to process a wide range of polymers in diameters of 50-300 nm into nonwoven webs of 0.1-5 gsm.

2.3. The contact angle and structure of the nanocomposite studies

The measurements of the contact angle of surface of polymer nanofibers covered by carbon films were carried out in atmospheric conditions at room temperature. A droplet of distilled water with the volume of 3 μl was released onto the sample surface. For each sample, at least three drops were released. Contact angle was designated by apparatus created in our institute. Samples covered by carbon coatings are presented in Figure 2.

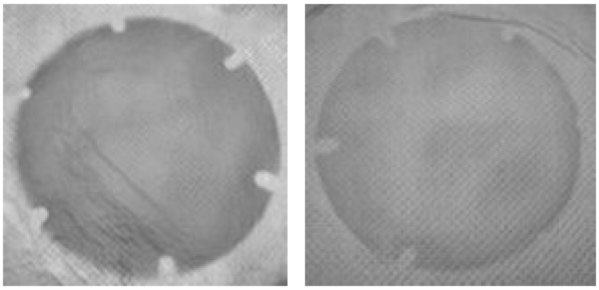

Fig. 2. samples covered by carbon coatings

The nanocomposite structure was analyzed by scanning electron microscope (SEM).

3. Results

3.1. The contact angle studies

Results of contact angle investigation indicated the radical improvement of hydrophobic properties for nanofiber textiles covered by carbon coatings. Only the carbon coating/PVC (samples devoid of warps) system has a hydrophilic property, with water droplets spread out across the surface of the polymer samples uncovered by a carbon layer; results are showed at Table 1.

Table 1.
Results of contact angle investigation

kind of substrate	PUR with basic fiberous material	PUR with out basic fiberous material	PVA with basic fiberous material	PVA with out basic fiberous material
character	hydrophobic	hydrophobic	hydrophobic	hydrophilic

3.2. Structure of the nanocomposite

The most essential result of this investigation is the fact that after carbon layer deposition the structure of material has not changed. The spaces between the nanofibers in the textile have not been closed by the material of the film. So, the functional properties of the nanofiber textile, mentioned below, remain unchanged. A SEM microscopic image of carbon film deposited onto a nanofiber textile is presented in Figure 3.

a)

b)

c)

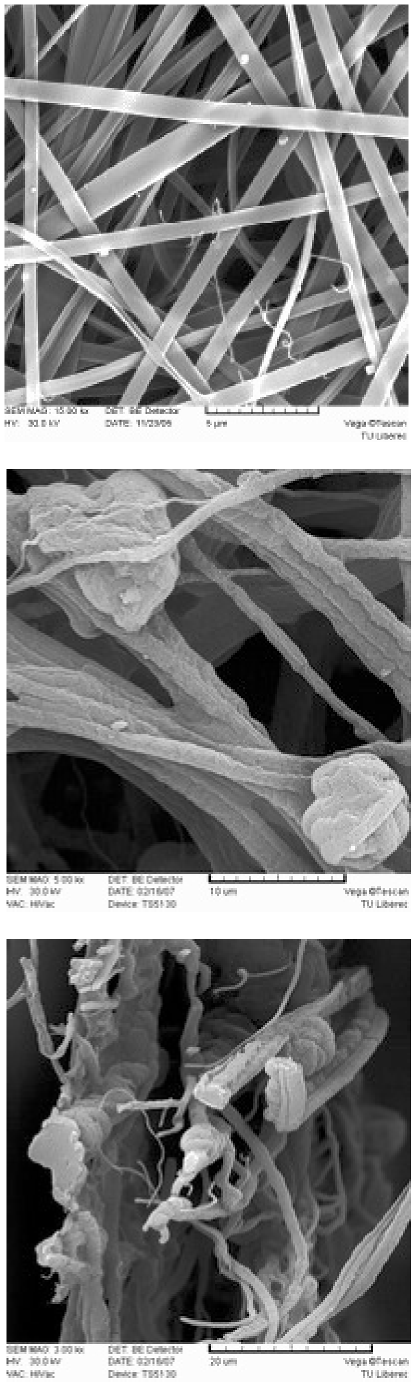

Fig. 3. SEM image of nanofiber textile a) uncovered, b) covered by carbon coatings, c) cross section of nanofibers covered by carbon coatings

4. Conclusions

In summary, we have shown that the carbon coatings can be deposited on the nanofiber textile produce by the Nanospider method at room temperature using the MW/RF PACVD technique.

The hydrophobic character of the covered surfaces has been proved. This fact confirms content of diamond phase in produced carbon coatings. This modification of nanofiber textile has not influenced the characteristic properties of substrate, the spaces between the nanofibers have not been closed by material of the film. Therefore, use of this nanocomposite makes possible the transport of oxygen and exudates. Since, distance between fibers is smaller than the dimensions of bacteria, the virus of influenza, or Human Immunodeficiency Virus (HIV) for example, this material is predicted to use as filter and wound dressing.

Moreover, it has to be underline that before synthesis of carbon coatings, nanofiber textile was working as mechanical filter. Deposition of carbon coatings makes possible the activation of nanofiber textile.

Acknowledgements

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References

[1] Z. Ma, M. Kotaki, T. Yong, W. Heb, S. Ramakrishna, Surface engineering of electrospun polyethylene terephthalate (PET) nanofibers towards development of a new material for blood, vessel engineering, Biomaterials 26 (2005) 2527-2536.

[2] B. Duan, X. Yuan, Y. Zhu, Y. Zhang, X. Li, Y. Zhang, K. Yao, A nanofibrous composite membrane of PLGA–chitosan/PVA prepared by electrospinning, European Polymer Journal 42 (2006) 2013-2022.

[3] J.P. Chen, G.Y. Chang, J.K. Chen, Electrospun collagen/chitosan nanofibrous membrane as wound dressing, Colloids and Surfaces A: Physicochemical and Engineering Aspects 313-314 (2008) 183-188.

[4] K. M. Yun, Ch. J. Hogan Jr., Y. Matsubayashi, M. Kawabe, F. Iskandar, K. Okuyama, Nanoparticle filtration by electrospun polymer fibers, Chemical Engineering Science 62 (2007) 4751-4759.

[5] H. Sarraf, L. Škarpová, P. Louda, Surfave modification of carbon fibers, Journal of Achievements in Materials and Manufacturing Engineering, 25 (2007) 24-30.

[6] S. Mitura, K. Mitura, P. Niedzielski, P. Louda, V. Danielenko, Nanocrustaline diamond, its synthesis, properties and applications, Journal of Achievements in Materials and Manufacturing Engineering 16 (2006) 9-16.

[7] S.E. Rodil, R. Olivares, H. Arzate, Properties of carbon films and their biocompatibility using in-vitro tests, Diamond and Related Materials 12 (2003) 931–937.

[8] W. Okrój, M. Kamińska, L. Klimek, W. Szymański, B. Walkowiak, Blood platelets in contact with nanocrystalline diamond surfaces, Diamond & Related, Materials 15 (2006) 1535-1539.

[9] R.M. Nowak, S. Jonas, S. Zimowski, K. Tkacz-Śmiech, Amorphous carbon layers on polymeric substrates, Journal of Achievements in Materials and Manufacturing Engineering 25/1 (2007) 23-26.

[10] J. Grabarczyk, D. Batory, P. Louda, P. Couvrat, I. Kotela, K. Bakowicz-Mitura, Carbon coatings for medical implants, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 107-110.

[11] O. Yasuharu, K. Hirakuri, K. Tsuchimoto, G. Friedbacher, O. Miyashita, Uniform deposition of diamond-like carbon films on polymeric materials for biomedical applications, Surface and Coatings Technology 184 (2004) 263-269.

[12] V.M. Elinson, V.V. Sleptsov, A.N. Laymin, V.V. Potraysay, L.N. Kostuychenko, A.D. Moussina, Barrier properties of carbon films deposited on polymer-based devices in aggressive environments Diamond and Related Materials 8 (1999) 2103-2109.

[13] S. Mitura, Nanodiamonds, Journal of Achievements in Materials and Manufacturing Engineering 24/1 (2007) 166-171.

[14] W. Kaczorowski, Synthesis of ultra nanocrystalline diamond by use dual freuqency plasma, in edited by S. Mitura, P. Niedzielski, B. Walkowiak “New technology for medical applications: studying and production of carbon surfaces allowing for controllable bioactivity”, NANODIAM, PWN, 2006, 41-45.

[15] O. Jirsak, F. Sanetrnik, D. Lukas, V. Kotek, L. Martinova, J. Chaloupek, WO2005-024101 (2005), Patent (Czech Republic).