Electrospun Aligned Polyethylene Oxide Nanofibers

WU De2zhi, SUN Dao2heng*
(Dept. of Mechanical & Electrical Engineering, Xiamen University, Xiamen Fujian 361005, China)

Abstract: An novel and facile electrospinning method, in which two parallel grounded metallic conductors are introduced to change electric field as auxilliary electrodes besides collector, is used to prepare oriented polyethylene oxide (PEO) nanofibers. SEMs of experiment results show that aligned nanofibers which di2 ameters are around 200~ 490 nm can be achieved by this one2step method, and the diameters of nanofibers decrease at first when the distance is smaller than 2 mm, then increase if the distance is larger than 2 mm with the increasing distance between two parallel conductors as the combination of strectching sufficiency and decreasing electric field strength. It also can be verified that the aligned nanofibers mainly caused by changed electrostatic field and not by structure.

Key words: electrospinning; aligned nanofibers; polyethylene oxide; auxilliary electrode
EEACC: 0560

电纺定向聚氧化乙烯纳米纤维

吴德志, 孙道恒*
(厦门大学机电工程系, 福建 厦门 31005)

摘　要: 采用一种新颖的纺丝工艺制备定向聚氧化乙烯纳米纤维. 该工艺就是将两个平行的接地金属导体置于收集板的两侧, 电镜图实验结果表明采用该一步法可以制得 200~ 490nm 左右的 PEO 定向纳米纤维, 而且随着电极之间距离的增大, 在拉伸的充分性和电场的共同作用下, 纳米纤维先减小后增大. 实验还证实定向纤维是电场而非结构作用的结果.

关键词: 电纺丝; 定向纤维; 聚氧化乙烯
中图分类号: TQ340. 64　　文献标识码: A　　文章编号: 100421699(2006)0521803204

Due to their remarkable characteristics of high sur2 face surface to volume ratio, unique optics, chemistry and mechanics[1] etc, polymer nanofibers, especially one2 dimensional nanofibers, will play important roles in fu2 ture applications, such as reinforced material, high per2 formance filters[2], high2sensitivity chemical sensor[3], tissue scaffolds[4,5], drug delivery[6], and so on. Elec2 trospinning which can be dated back in 1934[7] by Form2 hals A., is a straight, cost2efficient and convenient technology to fabricate polymer nanofibers. In a typical procedure, a high direct2current voltage is applied to a metallic needle, which is connected to a syringe filled with a polymer solution with enough viscosity and con2 ductivity. With the high voltage increasing, the electro2 static forces will overcome the surface tension of the pol2 ymer droplet suspended beneath nozzle of the needle to cause ejection of a fine jet. Undergoing solvent evapora2 tion, stretching and whipping instability, the charged jet turns into many continuous nanometer size fibers when reaching the grounded metallic collector.

收稿日期: 2006207201
基金项目: 海归学者科学研究基金资助; 厦门大学创新项目研究基金项目资助
作者简介: 吴德志(19772), 男, 博士研究生, 主要研究方向为纳米纤维和微机电系统等, wdz@xmu. edu. cn;
孙道恒(19642), 男, 教授, 博士生导师, 机械工程学会高级会员(通讯联系人), 主要研究方向为纳米纤维和微机电系统等, sundh@xmu. edu. cn.

Unfortunately, the nanofibers deposited on the collector are always randomly deposited and act as non2waven mat. As one2dimensional nanostructures are i2deal building blocks for hierarchical assembly of func2tional nanoscale electronic and photonic structure that could overcome fundamental and economic limitations of lithography based fabrication[8], many researchers all over the world have begun to mainly pay their em2phasises on how to achieve aligned nanofibers for fur2ther integration by electrospinning. Although the abili2ty to obtain oriented nanofibers remains a major chal2lenge in the field, some progress has been made and there are some literatures to cover it[9212]. A classical report example was reported that a thin rotating wheel with sharp edge was used to collect aligned nanofibers in[9]. The sharp edge is used to change applied electric field, which dominates the electrospinning process. However, the vital disadvantages of the setup are that the sharp edge is difficult to fabricate and the speed of wheel is hard to set because the speed of nanofibers is nonlinear and difficult to determine. Another technique is that 7, 500V AC potential with 60Hz frequency is used instead of DC potential by Royal Kessick et al[10]. But the fibers orientation degree is only to some ex2tent. Consequently, in this paper, a novel technique with electrospinning process is brought out, which is much easier to fabricate massively than previous work.

1 Experimental

Polyethylene oxide (PEO, average molecular weight M= 300, 000 g/ mol) purchased from Dadi Fine Chemical Co., Ltd. (Changchun, China) was used to prepare solutions that was used as the working fluid. PEO was dissolved in water and ethanol/ water solvent at different concentrations. All solutions were stored at room temperature. All experiments were performed with a setup showed as Fig. 1 at room temperature in air. The solutions were stored in the syringe. The anode of high po2tential power supply (DW2P40321AC, Tianjin Dongwen) (The voltage carried out is 9, 000V) is connected to the needle of syringe which inner di2ameter is about 0. 3 mm and the cathode is connect2ed to the metallic conductors, which are on the quartz substrate collector. A metallic plate, which is parallel to collector, is connected to needle to make electric field much more even. The distance between the end of needle and two near electrodes is about 9cm. Both cathodes are well grounded. When the high voltage source is on, the solutions can be pulled from the needle by electric field and turned into nanofibers collected on the regions of the quartz substrate and two near electrodes. Elec2tron Micrographs of the electrospun nanofibers were obtained by Germany LEO1530 scanning elec2tron microscope and XL30ESEM.

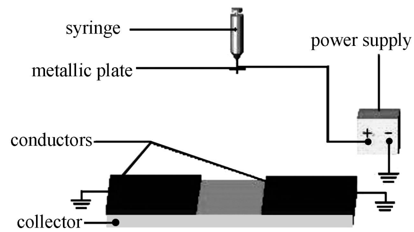

Fig. 1 Schematic diagram of the system setup

2 Results and discussion

As we all know, concentration, which affects viscosity, volume charge density, is one of the most important parameters in electrospinning process[13]. Drastic morphological changes were observed when concentration of polymeric solution was changed. From Fig. 2, it can be found that when concentration is smaller than 8%, most of them are beads and few fibers exist due to its low viscosity of solution. With the concentration in2creasing, more fibers come into being and beads disappear gradually. The SEM image of nanofibers

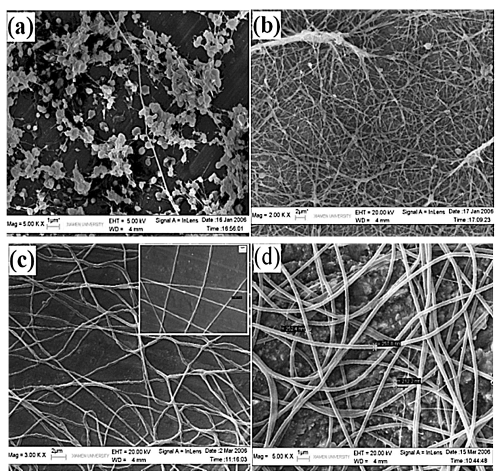

Fig. 2 SEM of fibers of (a), (b), (c) and (d) collected by conventional electrospinning from concentrations of 8%, 12%, 15% and 18% respectively in pure water.

in Fig. 2 show that in order to achieve uniform nanofibers, the concentration should be 18% at least when solvent is pure water. But if there are some ethonal, the concentration can be much more smaller. So in the following experiments the solu2tion of 15% (w/w) in 1/4 ethonal/H_2O is used as working solution.

Now the orientation morphology of nanofiers is studied. Scanning electron micrographs of nano2fibers deposited by setup of Fig. 1 are shown in Fig. 3. The images clearly illustrate that the nano2fibers are well aligned, which are perpendicular to the edge of the trench between two parallel grouned conductors. The results are caused by e2lectrostatic field, which is different to that of the traditional eletrospinning. As shown FEA diagram in Fig. 4a, the electric field forces on the trench be2tween two conductors are split into two fractions perpendicular to the edge of the conductors. Fig. 4b illustrates the electrostatic forces acting on a charged fiber. The induced charges on the elec2trodes mainly caused by high electro field are nega2tive, so the electric forces F_1 and F_2 are downward and point to electrodes respectively. Then the fiber will goes in the direction that the moment on the fiber is minimized.

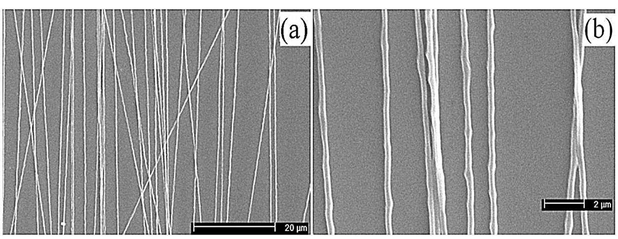

Fig. 3　SEMs of oriented PEO nanofibers. The deposition ime is 8 seconds. (a) and (b) are taken from the same sample.

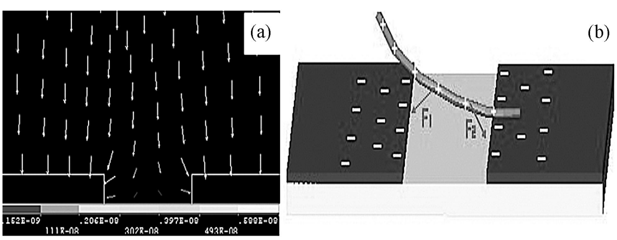

Fig. 4　(a) FEA of the electric field around the trench. In order to make the electric field strength more obvious, the distance between of the auxiliary electrodes and height between anode and collector are set to be 2mm and 5cm respectively. The high potential is set to be 9,000V. (b) Mechanical analysis of nanofiber between two conductors.

Therefore, the as2spun charged fiber therein is pulled along the direction upright to the edge of the e2lectrodes and aligned with each other when deposited on the quartz substrate. Two pairs of electrodes which is vertical to each other are introduced to prepare crossed nanofibers shown in Fig. 5.

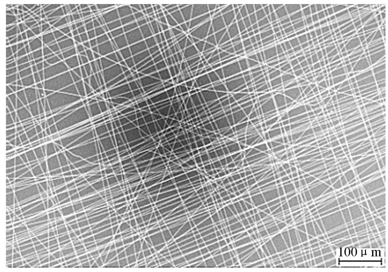

Fig. 5　Crossing PEO nanofiber deposited by two pairs of the electrodes. The distances are both 6mm

From experiments, it can also be found that the diameters of the nanofibers decrease to 210 ~ 265 nm at first when the distance of the two elec2trodes increase to 2 mm and then increase gradually with the distance increasing when the distance is larger than 2 mm, as shown in Fig. 6. we believe the reason is that when the distance is smaller than 2 mm, the stretching sufficiency of the as2spun nanofibers is not complete, then the diameters will decrease in spite of decrease of electric field strength with the distance increasing. But if the distance is larger than 2 mm, the diameters are dominated by electric field strength. Obviously, when the distance is increased, the diameters will increase with the electric field strength decreases.

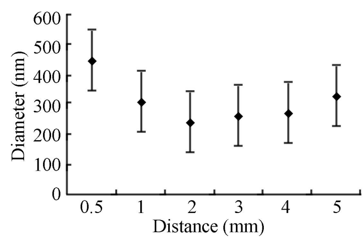

Fig. 6　Diameter of nanofiber as function of distance of two parallel conductors

In this paper, the experiments of other mate2rial of conductors are carried out too. The elec2trodes, which shape is as same as of the Fig. 1, made of quartz or silicon are tested. The nanofi2bers achieved by quartz electrodes and silicon elec2trodes are chaos and oriented respectively, as seen from Fig. 7. So it can be concluded that the orien2ted nanofibers are caused by the changed electro2static field and not by structure effect of elec2trodes.

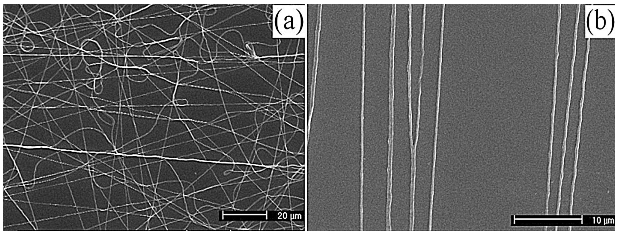

Fig. 7 SEM of nanofibers on quartz substrate between two parallel structure of (a) glass (b) silicon

3 ConclusionsP

In summary, a facile technique to fabricate o2 riented nanofiber is reported in this paper, which is that the separate and parallel conductors are atta2 ched between the collector. Expreriment results show that ① The diameters decrease at first within the distance of 2 mm due to the stretching suffien2 cy when the distance of the two electrodes is smal2 ler than 2 mm and then increase due to the decrea2 sing electric field strength when it is larger than 2mm. ② The aligned nanofibers is mainly caused by changed electric field, but not by structrue of e2 lectrodes. This technique offers a cost2effective technique to fabricate one2dimensional nanoscale " building blocks" that have potential in bottom2up assembly applications in such field as nanoelectron2 ics and photonics.

4 Acknowledgements

The project is sponsored by the Scientific Re2 search Foundation for the Returned Overseas Chi2 nese Scholars, Program for New Century Talents of Xiamen University and Program for Innovative Research Team of Xiamen University. The authors thank support of Nanotechnology Center of Xia2 men University.

参考文献:

[1] Yuris Dzenis. Spinning Continous Fiber for Nanotechnology [J]. Science, 2004, 304: 191721919.

[2] Phillip Gibson , Heidi Schreuder2Gibson, Donald Rivin. Transport Properties of Porous Membranes Based on Electro2 spun Nanofibers[J]. Colloids and Surfaces A: Physicochem. Eng. Aspects 1872188 , 2001: 4692481.

[3] Haiqing Liu, Jun Kameoka, David A. Czaplewski, and H. G. Craighead. Polymeric Nanowire Chemical Sensor[J]. Nano Letters. 2004, 4: 6712675.

[4] C. Y. Xu, R. Inai, M. Kotaki, S. Ramakrishna. Aligned Biode2 gradable Nanofibrous Structure: a Potential Scaffold for Blood Vessel Engineering[J]. Biomaterials, 2004, 25: 8772886.

[5] Jamil A. Matthews, Gary E. Wnek, David G. Simpson, and Gary L. Bowlin. Electrospinning of Collagen Nanofibers[J]. Biomacromolecules, 2002, 3: 2322238.

[6] Jing Zeng, Xiaoyi Xu, Xuesi Chen, Qizhi Liang, Xinchao Bi2 an, Lixin Yang, Xiabin Jing. Biodegradable Electrospun Fi2 bers for Drug Delivery[J]. Journal of Controlled Release, 2003, 92: 2272231.

[7] Formhals A. US Patent[P] 1, 975, 504, 1934.

[8] Yu Huang, Xiangfeng Duan, Qingqiao Wei, Charles M. Lieber. Directed Assembly of One2Dimensional Nanostructures into Func2 tional Networks[J]. Science, 2006, . 291: 6302633.

[9] Theron A, Zussman E and Yarin AL, Electrostatic Field2As2 sisted Alignment of Electrospun Nanofibres[J]. Nanotechnol2 ogy, 2001: 3842390.

[10] Royal Kessick, John Fenn, Gary Tepper. The use of AC Po2 tentials in Electrospraying and Electrospinning Processes[J]. Polymer, 2004, 45: 298122984.

[11] Paul D. Dalton, Doris Klee, Martin Moller. Electrospinning with Dual Collection Rings[J]. Polymer, 2005, 46: 6112614.

[12] Daoheng Sun, Chieh Chang, Sha Li and Liwei Lin. Near2 Field Electrospining[J]. Nano Letters. 2006, 16: 8392842.

[13] Xinhua Zong, Kwangsok Kim, Dufei Fang, Shaofeng Ran, Benjamin S. Hsiao, Benjamin Chu. Structure and Process Relationship of Electrospun Bioabsorbable Nanofiber Mem2 branes[J]. Polymer, 2002, 43: 440324412.