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Formation of periodic structures by surface treatments of polyamide fiber Part II. Low temperature plasma treatment

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Abstract

The processes of low temperature plasma treatment of polyamide fiber were systemically studied. Ripple-like structures in sub-micron size perpendicular to fiber axis were observed under particular treatment parameters. Suggested explanations were given of the mechanisms that produce the structure after the processes of plasma treatment. The fundamental approach used in modelling was considered the temperature profile of the material during the treatment. The morphological study results showed that the stress-field inside the fiber and the degree of crystallinity are essentially important in contributing to structure formation.
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Keywords: Surface treatment; Low temperature plasma; Polyamide fiber

1. Introduction

Low temperature plasma has been shown to be an effective treatment of modifying the surface properties of textiles. The major effects of plasma treatment on textiles can be seen in modifications of the physical nature of the fiber surface, the physical or chemical etching of the polymer, and changes in chemical characteristics of the treated surface [1]. In our previous papers, it was shown that when a polyamide fiber is treated by low temperature plasma, depending on the type of plasma gas and the energy level of the plasma, chemical modification or etching of the surface occurs [2–6]. Ripple-like structures in sub-micron size perpendicular to fiber axis are observed under particular treatment parameters (e.g. high energy-level or long treatment time). The ripple-like structures can be considered similar to, but on one order of magnitude smaller than, those induced by high-fluence laser. As we have discussed in Part I of this series, *temperature gradient* and *stress-field* are two important factors in determining the high-fluence laser induced structures [7]. It is interesting to study how these two factors affect the ripple-like structure formation by LTP treatment.

2. Experimental

The nylon 6 filaments (78 dtex 24 filament) from Teijin DuPont Nylon Ltd., Japan were used to produce plain woven fabrics. The fabrics were first washed with 1% non-ionic detergent solution (Lenetol B) in 70 °C water for 15 min and then rinsed with de-ionized water for another 15 min in order to minimize the chance of contamination. The samples were put in a standard conditioning room at 20 °C and 65% relative humidity for 24 h.

A glow discharge generator (SPP-001, Showa Company of Japan) was employed for the plasma treatment of the samples with oxygen gas. The applied discharge power and gas flow rate were 50–100 W and 50 cm^3 min^{-1}, respectively. The exposure time was varied from 10 to 60 min.

The morphology of the samples was investigated by scanning electron microscope, SEM (Lecia Stereoscan 440), for untreated and laser treated samples. All of the samples were gold coated prior to SEM examination.

3. Results and discussion

3.1. Temperature profile in the polyamide fiber

Plasmas are ionized gases. They consist of positive ions, negative ions, electrons, and neutral species. The mean energies

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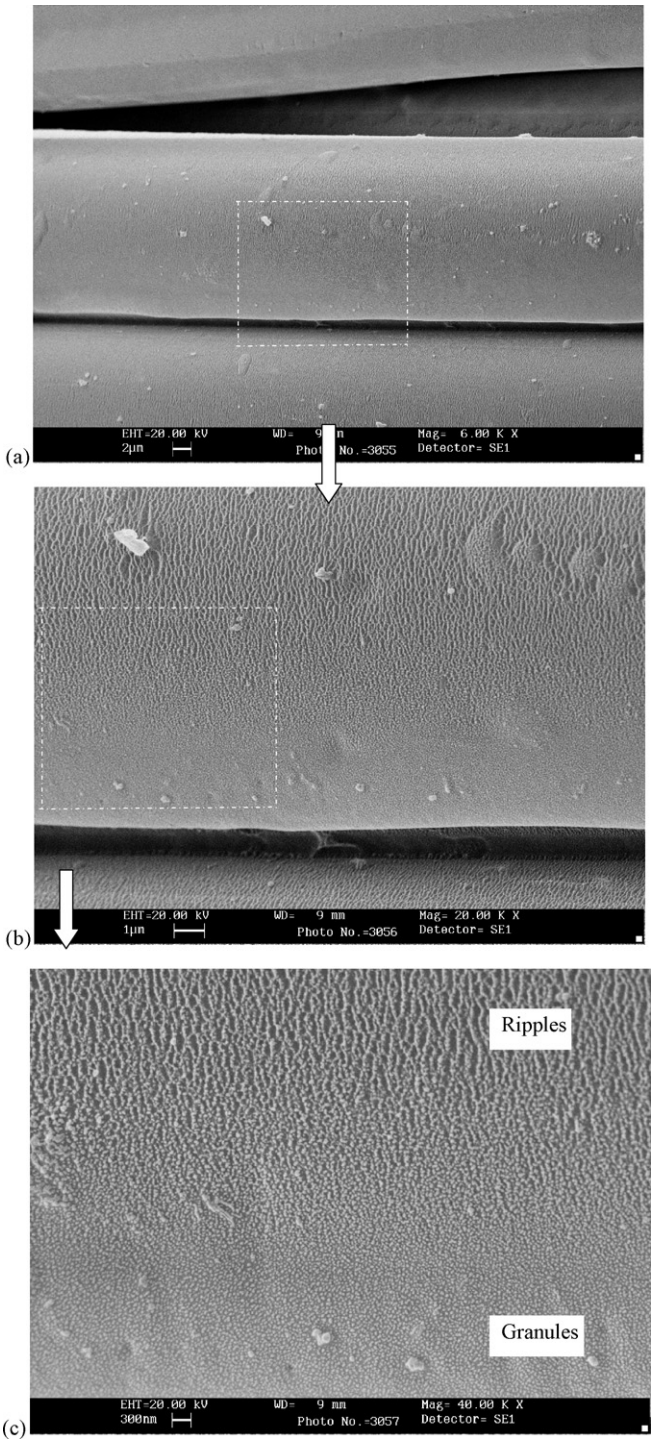

Fig. 1. Scanning electron micrographs of oxygen plasma treated polyamide fabric with 100 W discharge power and 10-min treatment time. (a) Magnification: 6000×; (b) magnification: 20,000×; (c) magnification: 40,000×.

of electrons and heavy particles are strongly different, owing to the low efficiency of energy transfer from electrons to molecules. The plasma electron mean energy of 4–9 eV formally corresponds to the effective temperature of about 50,000–100,000 K while the temperature of the neutral gas and materials being treated is as a rule not far from the room temperature [1]. Although the electrons or ions may have very high energies, the depth of these active species act in polymers only up to 10 monolayers. Therefore, it is assumed that no melting occurs on the polyamide surface during plasma processing (using moderate discharge power and treatment time) and no temperature gradient for the mobility of the molecules. The mechanism of ripple-like structures developed under low temperature plasma must be different from that of high-fluence laser treatment which described in Part I of this series [7].

3.2. Sub-micron ripples formation under LTP treatment

Experimental data showed that ripple structures are only observed under certain circumstances, such as high discharge power or long treatment time. It is suggested that plasma sputter etching is the main factor to induce these surface structures. The sputter yield depends on the energy of the bombarding species, the masses of projectile and target species, and the surface binding energy [8]. Consequently, there is no great difference between sputter yields for different materials. In the following section, ripple structure development will be first described, and then the effect of stress-field on the structure formation will be discussed.

Fig. 1a shows the oxygen low temperature plasma treated polyamide woven fabric (discharge power: 100 W, treatment

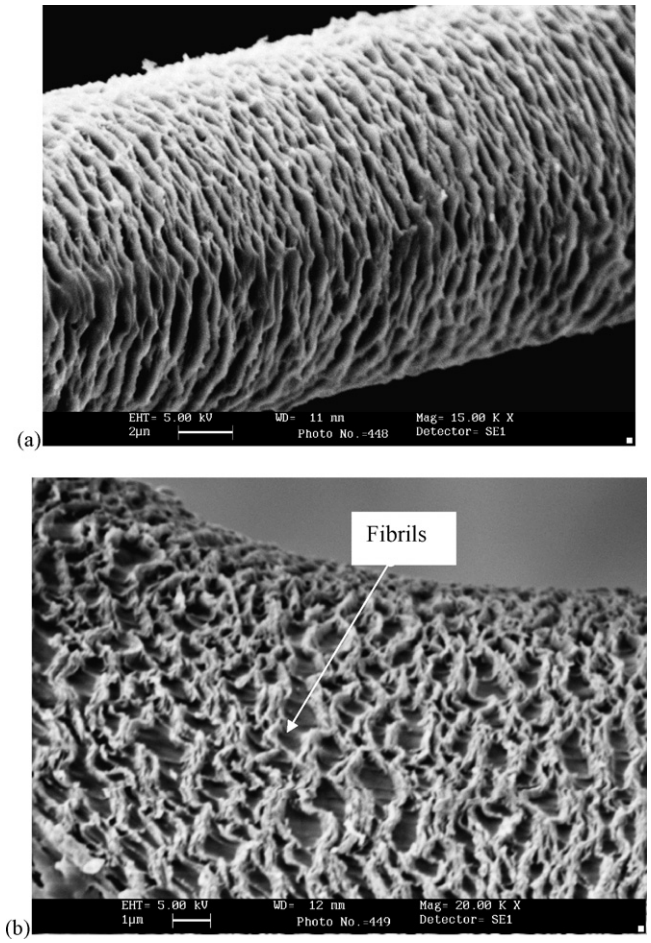

Fig. 2. Scanning electron micrographs of oxygen plasma treated polyamide fabric with 100 W discharge power and 60-min treatment time. (a) Titled at 45°; (b) titled at 80°.

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