

The preparation of low-background flexible electronics substrate based on ion beam modification of polymer surface

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The rare event detection experiments have always been updated with the improved performance of the electronics. In the next phase of China Dark Matter EXperiment (CDEX), the electronics have been designed with detector crystal barely immersed in 6.5 m shielding thickness of liquid nitrogen. The flexible electronic substrate (FES) composed electronics are required to be with high adhesion, low-temperature resistance and low-background. Polytetrafluoroethylene (PTFE) is widely recognized with properties of low-background, high dielectric but with poor surface adhesion. Here we focus on the comparative behavior of ion implanted polymers with cross-linking or chain scission dominant effects, and analyse the surface adhesion mechanism of polymers, to lay an important foundation for achieving electronic substrates with high adhesion, low-temperature resistance, and low-background.

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1. Introduction

The upgrading rare event detection experiments have become increasingly urgent with updating the performance of the electronics. In the next phase of China Dark Matter EXperiment (CDEX) [1], the electronics have been designed barely immersing in 6.5 m shielding thickness of liquid nitrogen with detector crystal, and the flexible electronic substrate (FES) composed electronics are required to be high adhesion, low-temperature resistance and low-background.

Polytetrafluoroethylene (PTFE) is not only widely recognized for its low background, but it also serves as the base layer of FES with the least adhesive force [2]. We previously published the preparation of FES based on different ions modified PTFE [3,4]. To solve the problem of poor surface adhesion, this paper proposes a new method for analyzing the surface adhesion of polymers, which provide direct insight into the influence of ion implantation on the polymer surface adhesion.

2. The different impacts on the polymer surface adhesion for different ion implantation conditions

Both nuclear and electronic stopping processes can cause polymer chain scission and crosslinking reactions. The difference is that the nuclear stopping process mainly leads to scission, while the electronic stopping process mainly causes cross-linking [5]. Thus, we explore the effects of crosslinking or scission reactions on the mechanical and electrical properties of polymer surfaces by setting different ion implantation conditions.

Table 1 summarizes the effects of different ion conditions on low-background PTFE and its related fluorocarbon polymers. The chemical changes indicate that the chemical effects caused by low keV ions in structurally similar polymers are similar, while the etching effects are varied. When the chain scission reaction promotes the formation of the three-dimensional weak boundary layer on the polymer surface, the fusion between the weak boundary layer and the transition layer is strengthened. With the repair of the weak boundary layer, the adhesion between the PTFE and the copper foil is significantly enhanced. At the same time, polymer dielectrics that maintain excellent dielectric properties at low-temperature can be obtained through ion implantation.

Table 1: Comparison of FES performance made by different ion implantation conditions

Characterization	160 keV Nitrogen ion implantation (PTFE and FEP) [3]	8 keV Nickel ion implantation (PTFE and PTFE-composite film) [4]
SRIM simulation	Nuc. Stopping Power = 48 eV/nm Elec. Stopping Power = 280 eV/nm	Nuc. Stopping Power = 934 eV/nm Elec. Stopping Power = 35 eV/nm
SEM/AFM	Surface roughness increases with fluence	The significant increase in height and steepness of surface greatly enhances the mechanical anchoring force
Spectra	C=C sp ² bonds increases with fluence, & PTFE>FEP. Polar small molecules such as C=O and C=N bonds were introduced at low fluence	C=C sp ² bonds Forming chemical bonds with nickel ions, & PTFE>FEP

Contact angle & Surface energy	As the fluence increases, it first increases and then decreases	Enhanced hydrophobicity and increased surface energy
Adhesion force (peel strength)	Due to the enhancement of surface roughness, the adhesive force of PTFE-FES increases with increasing dosage and is greater than that of FEP-FES	The binding force is significantly superior and can last for 20 days in liquid nitrogen immersion. The adhesion force of PTFE-composite film based FES is greater than that of PTFE-FES
Dielectric performance	10^{16} ions/cm ² -PTFE-FES has excellent electrical properties, and the surface resistance remains unchanged after immersion in liquid nitrogen.	At room temperature and 273 K, the electrical performance of PTFE-composite film FES is better, but the electrical performance of PTFE FES can be maintained to 173 K

3. Mechanical and electrical performance of self-developed PTFE FES

The adhesion of self-developed FES after soaked in liquid nitrogen for 20 days is not less than 0.67 N/mm, demonstrating good low-temperature resistance. In addition, the dissipation factor of the self-developed FES is less than 0.003 at 173 K, which is better than 17 times that of commercial FES products.

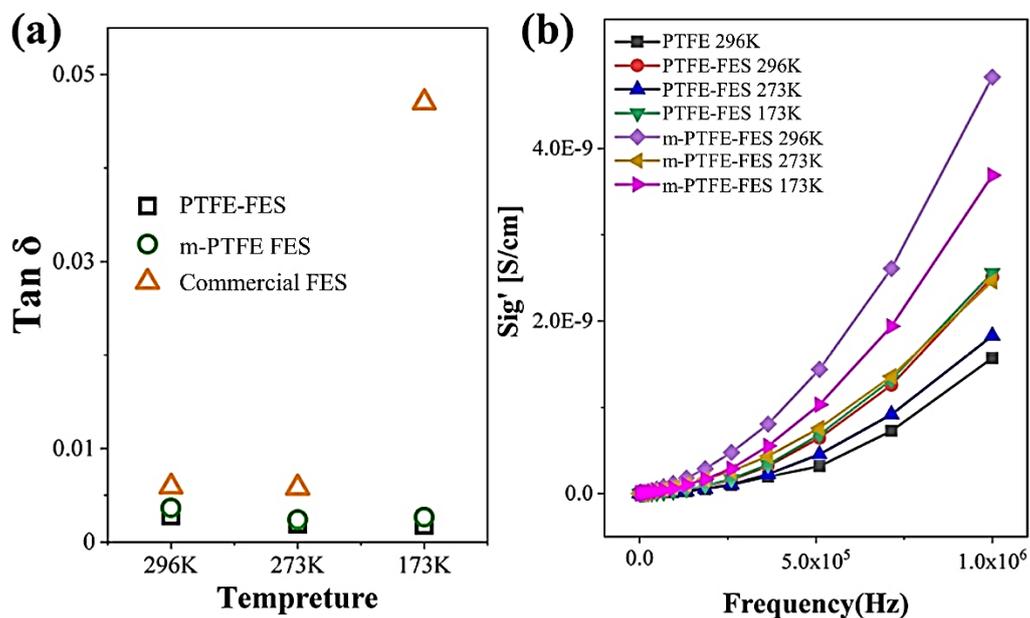


Figure 1: Dielectric losses of PTFE FES, m-PTFE FES (PTFE-composite film based FES), and commercial FES at different temperatures at 10^6 Hz; (b) AC Conductivity of PTFE, PTFE FES, and m-PTFE FES at 0- 10^6 Hz Frequencies at Different Temperatures.

4. Low-background performance of self-developed PTFE FES

The background source of FES in rare event detection experiments should mainly meet the control requirements of uranium, thorium, potassium and their sub chain nuclides concentrations. The results show that the specific activity of ^{214}Pb (^{238}U) in the self-developed PTFE FES was less than 95.2 ± 27.3 mBq/kg, while the specific activity of ^{214}Pb (^{238}U) in commercial PTFE FES was higher than 200 mBq/kg in both tests, under the same measuring equipment. The self-developed

PTFE FES performance has lower background, and it's the reason that ion implantation modification as the surface controlling method has been a contributing factor.

Table 2: Background measurement results of PTFE FESs

N o.	Nuc- lides	Energy (keV)	Specific activity (mBq/kg)				
			Measured in CJPL			Data from papers	
			self-developed PTFE-FES	commercial FES CuFlon		commercial FES CuFlon	
1	²¹⁴ Pb (²³⁸ U)	351.93	<95.2±27.3	235.9±19.8	303.9±15.9	<130 (²³⁸ U) [6]	<40 (²¹⁴ Pb) [7]
2	²⁰⁸ Tl (²³² Th)	583.188	<23.5±11.6	19.9±5.0 (MAD)	<8.8	<1.9 (²²⁸ Th)	<30 (²⁰⁸ Tl)
3	⁴⁰ K	1460.7	<462.1±176.4	<160.6±69.3	<95.4	48±15	<400±200

5. Conclusion

In this article, the structure-activity relationship of ion implantation modification polymer surfaces was studied, which provides a theoretical basis and practical example for the development of high adhesion, low-temperature resistance and low-background PTFE FES.

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