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Enhanced Cytocompatibility and Reduced Genotoxicity of Polydimethylsiloxane Modified by Plasma Immersion Ion Implantation

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Introduction

Polydimethylsiloxane (PDMS) which is flexible, thermo-tolerant, resistant to oxidation, and tunable in hardness is very promising in microelectronics encapsulation. [1,2] In the biomedical field, PDMS is particularly suitable as contact lenses and implants [3,4] on account of its transparency, high gas permeability, and long-term durability in aqueous solutions. Nevertheless, PDMS with the basic structure of $(\text{-OSi}(CH_3)_2\text{-})_n$ has many methyl groups ($-CH_3$) and the surface free energy of PDMS is quite small (22–25 mJ/m^2). [5] The inherent hydrophobicity and concomitant biocompatibility inadequacy have hitherto restricted the application of PDMS in biomedical engineering. Plasma immersion ion implantation (PIII), a non-line-of-sight plasma- and ion-beam-based surface treatment technique, is particularly suitable for biomedical devices with an irregular shape. [6,7] By using different plasma gases, PIII can create different chemical groups on the surface of different types of samples including PDMS to enhance the biological performances.

Materials and Methods

O_2 plasma exposure and O_2 PIII were conducted on the PDMS samples. The surface morphology was examined by profilometry and scanning electron microscopy. The CHO cells were seeded at a density of 2×10^4 cells per sample on 24-well tissue culture plates. After incubation for 2 days, the samples were fixed to determine the cell morphology by fluorescent stain. The cell viability was studied by the MTT assay, and the corresponding genotoxicity was evaluated by the cytokines block micronucleus (MN) technique.[8] The relative level of superoxide anion ($O\cdot_2^-$) was stained by hydroethidine (HE, an indicator of $O\cdot_2^-$, Invitrogen) and determined by fluorescence microplate assay and fluorescence microscope.

Results and Discussion

In contrast to the flat morphology observed from PDMS and plasma exposure PDMS (P-PDMS), wrinkled “herringbone” patterns with lateral feature several micrometers in size are observed from the surface of PIII-PDMS (Figure 1). As shown in Figure 2, the CHO cells on PDMS exhibit a spherical morphology with lack of F-actin organization. In contrast to PDMS, the CHO cells spread more on P-PDMS and the elongated cells on PIII-PDMS are comparable to those on the culture plate abundant with F-actin in the skeleton. The MTT assay revealed that the viability of the CHO cells follows the following order: PIII-PDMS > P-PDMS > PDMS. As one of the possible factors inducing MN, intracellular ROS is evaluated by involving DMSO (a scavenger of ROS) after CHO cells have been cultured for 2 days. The result in Figure 3 shows that addition of 0.1% DMSO treatment

decreases the MTT and MN frequency on P-PDMS, indicating that cells on PDMS and P-PDMS exist with intracellular ROS. In addition to the assays involving DMSO, the intracellular level of $O\cdot_2^-$ is further evaluated by the assay of hydroethidine (HE) staining and Figure 3 shown that the intracellular $O\cdot_2^-$ on PIII-PDMS is much lower than those on PDMS and P-PDMS, and even as low as that on the cell culture plate. The intracellular $O\cdot_2^-$ assay results are consistent with those of MN suggesting that PIII-PDMS has much lower genotoxicity than PDMS and P-PDMS.

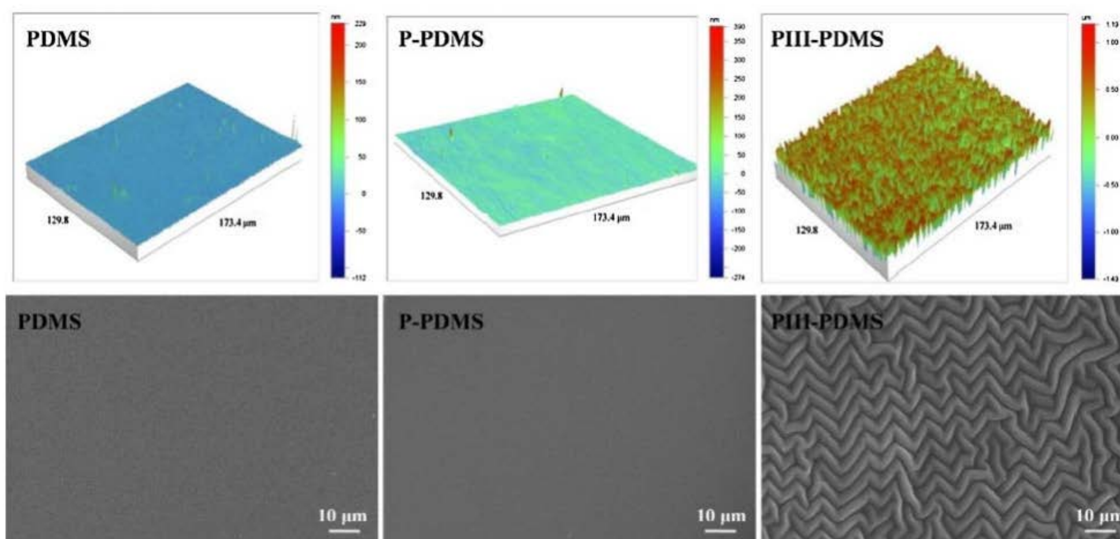

Figure 1. 3D pictures (top), and SEM images (bottom) acquired from PDMS, P-PDMS, and PIII-PDMS with PIII-PDMS showing the wrinkled "herringbone" patterns.

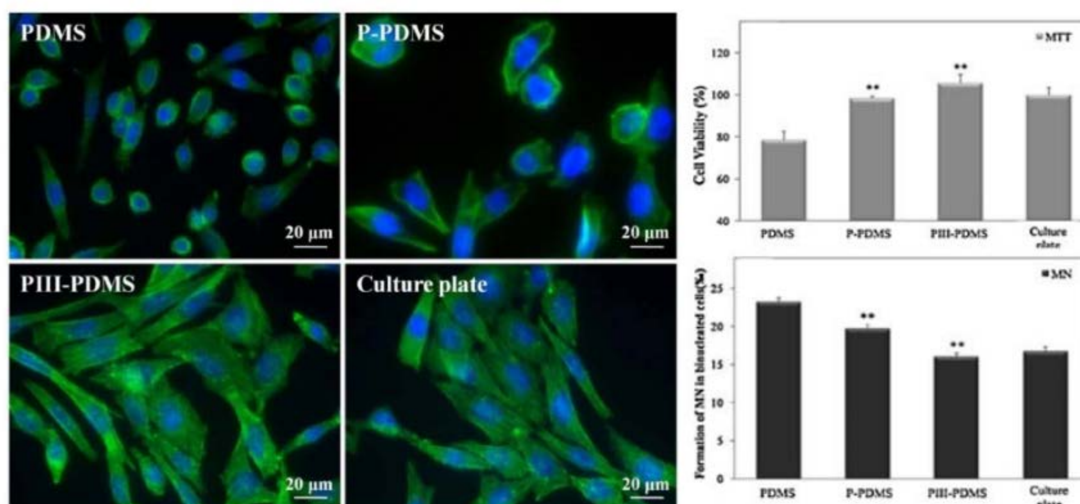

Figure 2. Morphology of the CHO cells on PDMS, P-PDMS and PIII-PDMS after 2 days with the green fluorescence referred to cytoskeleton and blue fluorescence referred to the nuclei. The relative cell viability, and Micronuclei formation of CHO cells on PDMS, P-PDMS and PIII-PDMS after 2 days. The student's t-test is utilized to determine the level of significance and ** stands for $p < 0.05$.

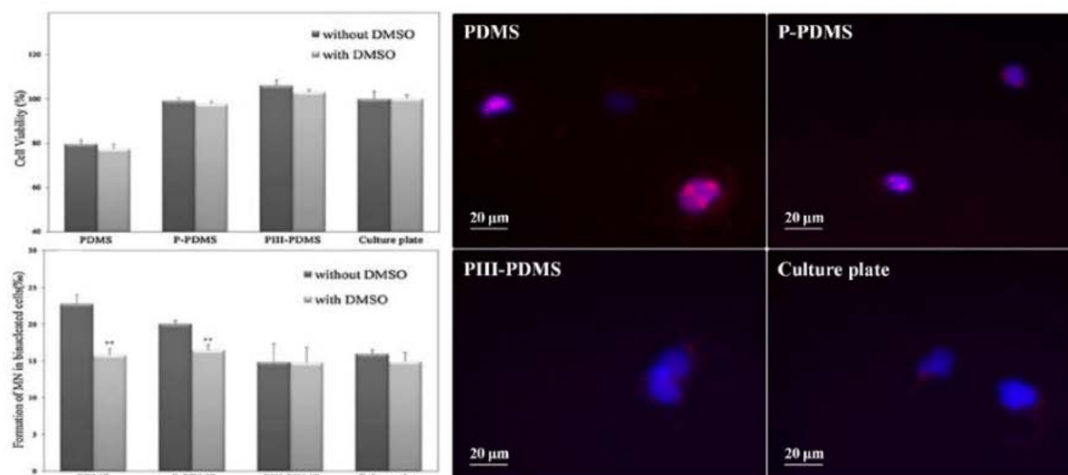

Figure 3. The relative cell viability and micronuclei formation of CHO cells on PDMS, P-PDMS, and PIII-PDMS after 2 days with or without DMSO addition. HE staining and quantitative determination of the intracellular superoxide anion after culturing on PDMS, P-PDMS, and PIII-PDMS for 1 day. The student's t-test is utilized to determine the level of significance and ** stands for $p < 0.05$.

Conclusion

Plasma immersion ion implantation is employed to modify the surface properties of PDMS. Different with simple plasma exposure, O_2 PIII not only produces wrinkled "herringbone" patterns on the PDMS surface, but also improves the surface hydrophilicity. The PDMS samples after PIII have better cytocompatibility and lower genotoxicity than both the untreated and plasma exposed sample and the performance is even comparable to that observed from the culture plate. PIII is demonstrated to be a viable and effective way to improve the surface properties of PDMS in biomedical applications.

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