DLC 膜を用いた低摩擦・高効率の滑り型摩擦発電システムの開発

Development of DLC-based sliding-TENG with low friction and high efficiency

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1. Introduction

Triboelectric nanogenerators (TENGs) have shown promising potential in IoT application in recent years due to their distinguish properties. Sliding mode TENG has higher charge transfer efficiency than contact separation mode. However, since most of the dielectric materials of TENG are made by organic polymers, the durability of the device is still a challenge for the development of sliding mode TENG. In this work, Si-incorporated diamond-like carbon (Si-DLC) films were applied to sliding-mode TENG as non-polymer dielectric materials to increase the output and reduce the abrasion at the same time. The work of Si-DLC based TENG shows a promising application prospect in a real mechanical system.

2. Results and discussion

DLC films were deposited on pure Aluminum and Si substrates by using the bipolar-type plasma based ion implantation and deposition (PBII&D) technique [1, 2]. Toluene ($C_6H_5CH_3$) and a mixture of Tetramethylsilane ($Si(CH_3)_4$, TMS) and Toluene were used as the source gases for H-DLC and Si-DLC films, respectively. To simplify the expression of different Si-DLC films, the Si-DLC films with different TMS ratio were named as TMS 2 (20 % TMS), TMS 4 (40 % TMS), TMS 6 (60 % TMS), and TMS 8 (80 % TMS). The fabricated sliding-mode TENG is shown in **Fig. 1** (a) and (b). A commercial reciprocating friction tester was used for the TENG experiments. An acrylic plate was used as a substrate, and thin Al tape was pasted on the acrylic plate as an electrode. Two pieces of polytetrafluoroethylene (PTFE) was paved on the Al electrodes. DLC films were deposited on the upper Al electrode that was attached to an acrylic plate. The tribological properties of diamond-like carbon films were test by ball-on-disc friction meter. The experimental configuration is shown in **Fig. 2**. 3/16 in diameter Teflon balls were used for testing. The speed and applied normal load are 1 Hz and 0.49 N, respectively.

To understand the microstructures of DLC films, Raman spectrum was employed to analysis as it is a useful non-destructive method. It can be found that both the I_D/I_G ratio and G-peak position decrease with increasing Si content from Raman results. The Si-incorporation results in an opening up of the sp^2 rings and dropping of the sp^2 cluster size because the Si atoms cannot form the π bonds, leading I_D/I_G ratio decreases with the increasing Si content [2]. These behaviors display that the sp^3 bonds rise with the increasing Si content in the Si-DLC film [3]. The full-width at half maximum of G-peak (FWHM(G)) can indicate the structural disorder resulting from bond angle and bond length distortions of the DLC film structure [3]. FWHM(G) goes up with the disorder increases [4, 5]. Choi et al. [2] have reported that Si incorporation to DLC film can increase an amount of dangling bonds, meaning more possible electron-donating sites increase, which are beneficial for TENG charges accumulation [6, 7]. From the results Raman analysis, FWHM(G) rises gradually with the increase of TMS ratio and reach the maximum point when the ratio reaches 60% and 80%. Therefore, TMS 6 and TMS 8 may have relatively higher electron-donating ability thus higher triboelectric output.

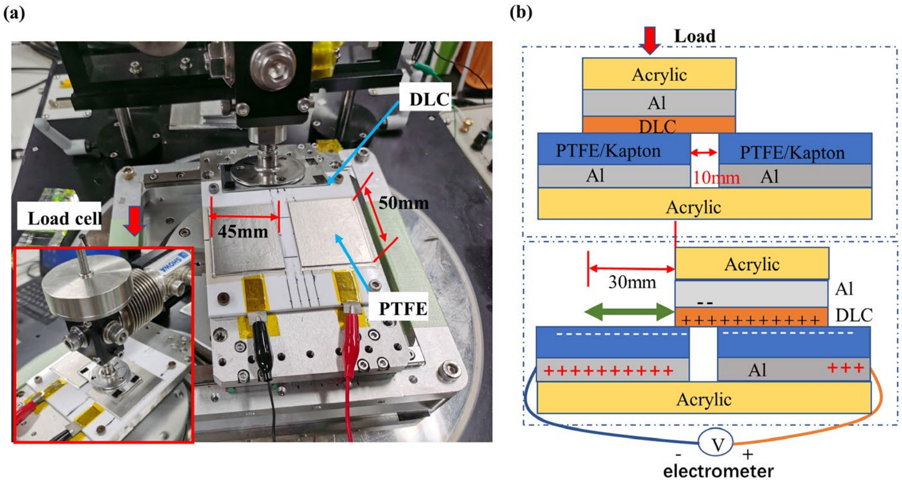

Fig. 1. Sliding-mode TENG: (a) Experimental setup and (b) schematic diagram.

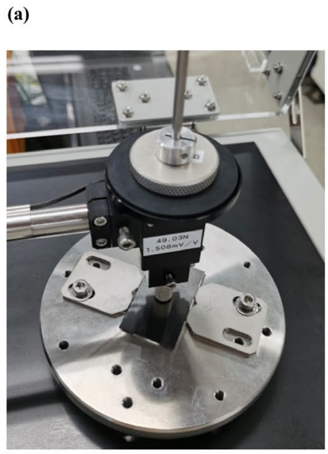

Fig.2. Ball-on-disc tribometer.

To compare the tribological performance of the H-DLC and TMS 8, ball-on-disc experiments were conducted. From the ball-on-disc experiment, it can be found that the COF of TMS 8 is the lowest among all the prepared DLC films. The wear scar of PTFE balls slid against the TMS 8 is smaller and smoother than that of H-DLC. These results indicate that TMS 8 show better anti-abrasion performance comparing with H-DLC.

To explore the relationship between the output and the ratio of TMS, PTFE was selected as counterparts under the freestanding mode to carry out TENG experiments. The reciprocating stroke was 30 mm, and the gap between the two PTFE (Kapton) was 10 mm. From PTFE/DLC pair experiments, the V_{oc} (open circuit voltage) and I_{sc} (short circuit current) of TMS 8 are approximately twice of those of H-DLC. From the experimental results presented in **Fig. 3**, V_{oc} and I_{sc} open circuit voltage of TMS 8 increase more than 4 times than that of H-DLC, which is in line with the analysis of Raman results. Furthermore, the based on the experiment of different working frequency, I_{sc} can change with the working speed linearly, which is possible used as speed sensors. These results indicate that TMS 8 has a distinguish triboelectric properties as non-polymer dielectric materials for TENG.

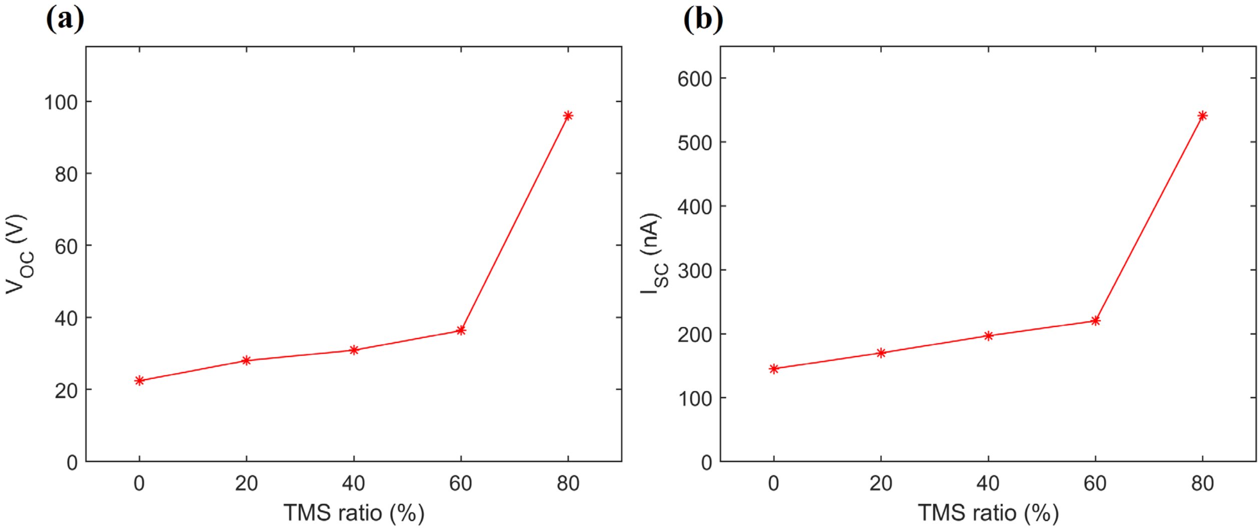

Fig. 3. (a) Open circuit voltage and (b) short circuit current with the ratio of TMS.

3. Conclusion

For Si-DLC based TENG, it has a promising application perspective in a mechanical system, as the thickness is very thin, normally several micrometers. Therefore, it can be applied as monitoring sensors or power sources without changing the original mechanical structures. In this study, Si-DLC films with different TMS ratios were systemically compared, and the optimal TMS ratio was given for the first time. The Si-DLC with a TMS ratio of 80% shows the largest output performance. One of the reasons is the disorder of the clusters which may provide more electron donating sites, leading to an electron-donating ability enhancement. Further, the tribological properties was explore by ball-on-disc experiment, and TMS 8 also display better anti-abrasion performance. With the advantages of mechanical properties, such as durability, low friction and ease to apply in a mechanical system without any structural change, Si-DLC has great potential as a dielectric material for TENG.

References

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