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Research Highlight

Quantifying electron-transfer in liquid-solid contact electrification

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Since the triboelectric nanogenerator (TENG) was invented by Prof. Zhong Lin Wang's group in 2012, triboelectric power has gradually attracted the attention of researchers as a new energy harvesting technology. So far, TENGs have entered many fields, and have made breakthrough progress in the applications. At present, Prof. Zhong Lin Wang has pointed out that the working nature of TENG is based on the combined effect of contact electrification and displacement current [1]. When related to contact electrification, although several experimental results have provided clear evidence that electrons are dominant carriers in contact electrification between solids, there is still difficulty in illustrating the contact electrification between solid and liquid purely counting on electrons.

For TENGs, it is very important to clearly understand the phenomenon and process of solid-liquid contact electrification, which contributes to discovering the physical formation of electric double layer (EDL) in the solid-liquid interface. A latest work digs into the huge power in solid-liquid contact. When a 100.0 μL droplet released from a height of 15.0 cm comes into contact with a droplet-based electricity generator device, the power generated by solid-liquid contact can immediately light up 100 commercial LEDs. In this condition, PTFE film captures a large amount of static charge, and electrostatically induces the same amount of opposite charge due to EDL between the solid-liquid interfaces [2]. The EDL refers to a microcosmic charge distribution at the solid-liquid interface, and it is formed based on attracting opposite charges by the solid surface in a liquid. For a long time, the charged surface of solid in an EDL is considered to be due to ion adsorption or surface ionization reaction. Recently, according to the basic principle of contact electrification, Prof. Zhong Lin Wang has proposed a novel two-step model of formation mechanism of EDL, which illustrates that EDL starts with electron transfer and then turns into physical or chemisorption process of ions [3,4]. To demonstrate this model, under the leadership of Prof. Zhong Lin Wang, Dr. Shiquan Lin, from the Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences, uses microcosmic testing methods to prove that the electron transfer exists in solid-liquid contact electrification, which even dominates on some material surfaces [5].

The research studies the temperature effect of contact electrification between ceramic materials such as SiO_2, MgO, Si_3N_4 and liquids such as deionized water, aqueous NaCl, HCl and NaOH solution, in order to demonstrate the existence of electron transfer between the solid and liquid based on the principle of thermionic emission. In previous reports, contact electrification between the ceramic material and the aqueous solution is mainly due to ionization reaction to generate charged ions connected to the solid surface atoms by covalent bonds, so these ions are not easy to be excited by heat. According to the previous experimental phenomena of solid-solid contact electrification [6,7], when the solid surface is heated to above 353 K, a large number of electrons are discharged, and the dissipate rate is in accordance with thermionic emission model. In the same way, the ceramic material charged by liquid is heated to a specific temperature, and the real-time change in the surface charges is measured with a Kelvin probe force microscope (KPFM), as shown in Fig. 1. The results show that the surface of SiO_2 is negatively charged after contacting with deionized water. The charge density begins to decay at a temperature of 353 K, and the rate of dissipate increases with increasing temperature, as shown in Fig. 1c. This phenomenon is in accordance with thermionic emission, so it is considered to be the evidence that electron transfer exists in solid-liquid contact. But it is worth noting that even when the temperature reaches 513 K, there is still a small part of the sticky charges on the solid surface in Fig. 1d. According to experimental results, 77% of the charges in the first contact between SiO_2 and deionized water are removed by heating and considered to be electrons, and the immovable parts are ionic charges generated by ionization reaction.

Furthermore, the research team studies the contact electrification between SiO_2 and different aqueous solutions, and finds that increase in the concentration of NaCl solution will reduce the amount of electron transfer between the SiO_2 and the solution. And changes in the pH of the aqueous solution will affect the process of ionization reaction and ion transfer between SiO_2 and the solution. On the other hand, the contact electrification between various solids and deionized water also shows the difference, due to the large difference in the ratio of electron transfer and ion transfer from contacting pairs. For example, the ratio of electron transfer and ion transfer for MgO and deionized water is 0.62, and the ratio for AlN and deionized water is 7.47. The authors

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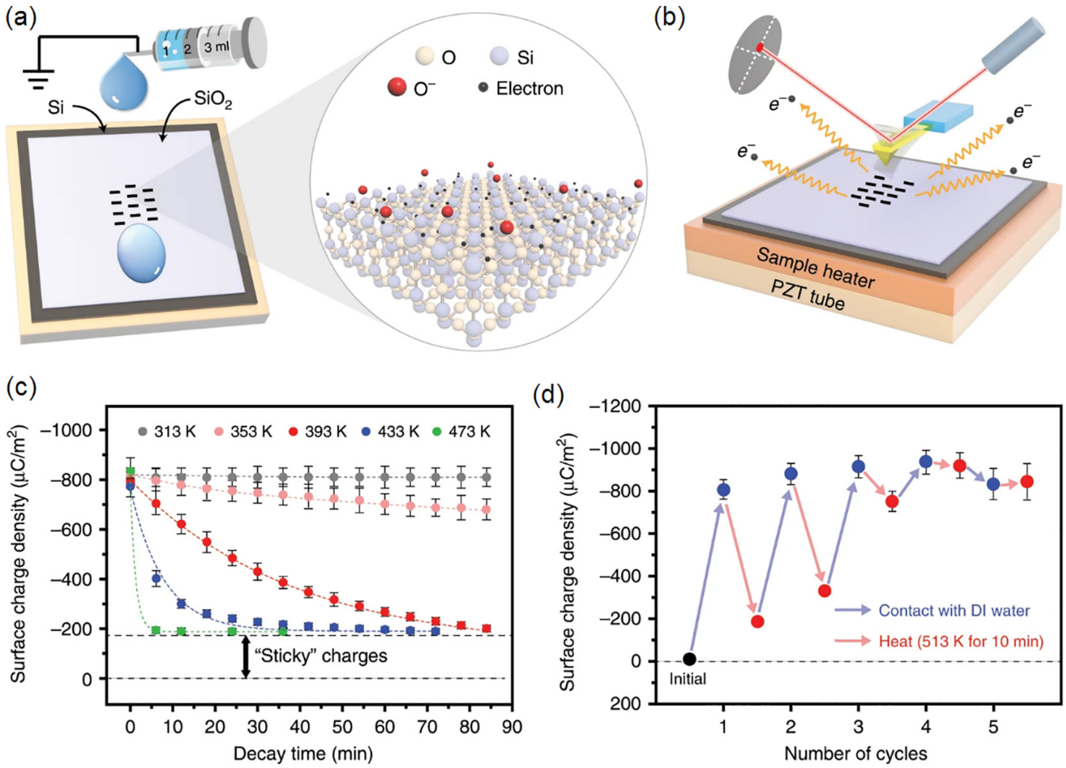

Fig. 1. Temperature effect on the contact electrification between the deionized water and the SiO_2. (a) The setup of the charging experiments for contact electrification. (b) KPFM platform for the thermionic emission experiments. (c) The decay of charge density on the SiO_2 surface at different substrate temperatures. (d) The contact electrification charge density on the SiO_2 sample surface in the charging and heating cycle tests [5]. Copyright 2020 © Springer Nature.

relate this phenomenon to the difference in contact angle between different solids and deionized water. And hydrophobic materials are more prone to electron transfer, because the stronger interaction between the surface of hydrophilic material and water molecules generates the sticky ions on the hydrophilic surface.

In summary, the results from the team show that there is always electron transfer during the contact electrification between solid and liquid, and electron transfer is the majority in some cases. This provides an important experimental evidence for the two-step model about the formation of EDL, in which the electron transfer plays a dominant role in solid-liquid contact electrification.

Conflict of interest

The authors declare that they have no conflict of interest.

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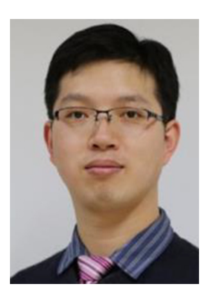

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