

Effect of Photo-Excitation on Contact Electrification at Liquid–Solid Interface

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Cite This: <https://doi.org/10.1021/acsnano.1c03358>



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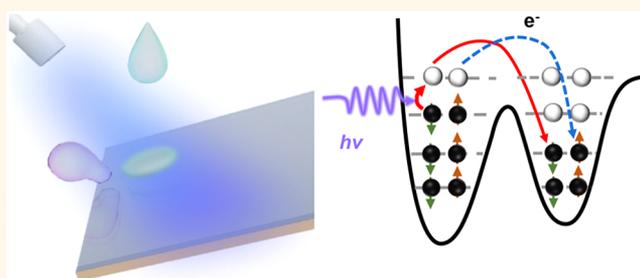
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Supporting Information

ABSTRACT: Liquid–solid triboelectric nanogenerator (L–S TENG) is one of the major techniques to collect energy from tiny liquids, while the saturated charge density at the L–S interface is the key element to decide its performance. Here, we found that the saturated charge density of L–S contact electrification (CE) can be further increased under the illumination of an ultraviolet (UV) light. The fluorine-containing polymers and SiO₂ are chosen as the electrification materials and with and without UV illumination on the L–S TENG. A series of experiments have been done to rule out the possible influences of anion generation, chemical change of solid surface, ionization of water, and so on. Therefore, we proposed that electrons belonging to water molecules can be excited to high energy states under UV illumination, which then transfer to solid surface and captured by the solid surface. Finally, a photoexcited electron transfer model is proposed to explain the enhancement of CE under the UV illumination. This work not only helps to further understand CE at L–S interface, but also offers an approach to further enhance the performance of L–S TENG, which can promote the TENG applications in the field of microfluidic systems, liquid energy harvesting, and droplet sensory.

KEYWORDS: contact electrification, liquid–solid TENG, photoexcitation, electron transfer, saturated charge density



INTRODUCTION

Contact electrification (CE) and the related static charge generation on the surface of various materials have been known for more than 2600 years.^{1,2} However, the fundamental mechanism and influencing factors of CE were not fully revealed until now. In particular, CE on liquid–solid (L–S) interface is more complicated, owing to the coexist of liquid molecule and free ions, while CE at the L–S interface may also have great impact on the formation of the electric double layer (EDL) of surface chemistry.^{3,4} Meanwhile, a L–S triboelectric nanogenerator (TENG), which is based on the CE at L–S interface, has been demonstrated to harvest various water energies, including raindrop,^{5–8} water wave,^{9–11} microfluidics,^{12–14} and so on. Previous studies have verified that the continuous dripping of droplets on the solid surface leads to the charge saturation phenomenon on the electrified surface, while the screen effect can still induce displacement current for energy generation even after charge saturation.^{15,16} In this case, the saturated surface charge density is a quite important parameter for the L–S TENG. So far, a plenty of methods have been proposed for increasing the saturated charge density of L–S TENG, such as the modification of surface morphology,¹⁷ charge injection¹⁸ or the design of chemical structure.^{19–21} Recently, Wang proposed a hybrid model for elucidating the

formation of EDL with the consideration of both electron transfers, the ionization reaction, and the electrostatic ion adsorption.^{2–4} With the development of physical study of CE at L–S interface, many different approaches can be inspired to further elevating the saturated surface charge density of L–S TENG.

It is generally believed that common UV light, although having short wavelength and high energy, has little effect on a water molecule because no absorbance and no enhancement of dissociation are observed in bulk water.^{22,23} Only the energy of extreme ultraviolet or soft X-rays is sufficient to dissociate water and allow it to participate in some photochemical reactions. Some studies have found that extreme ultraviolet can promote the dissociation of water at the interface of water–metal or another interface,^{24–26} and water has a certain absorptivity on extreme ultraviolet. Under soft X-ray pluses with higher energy, a valence hole (H₂O⁺) is created and a proton-transfer reaction

Received: April 21, 2021

Accepted: June 4, 2021



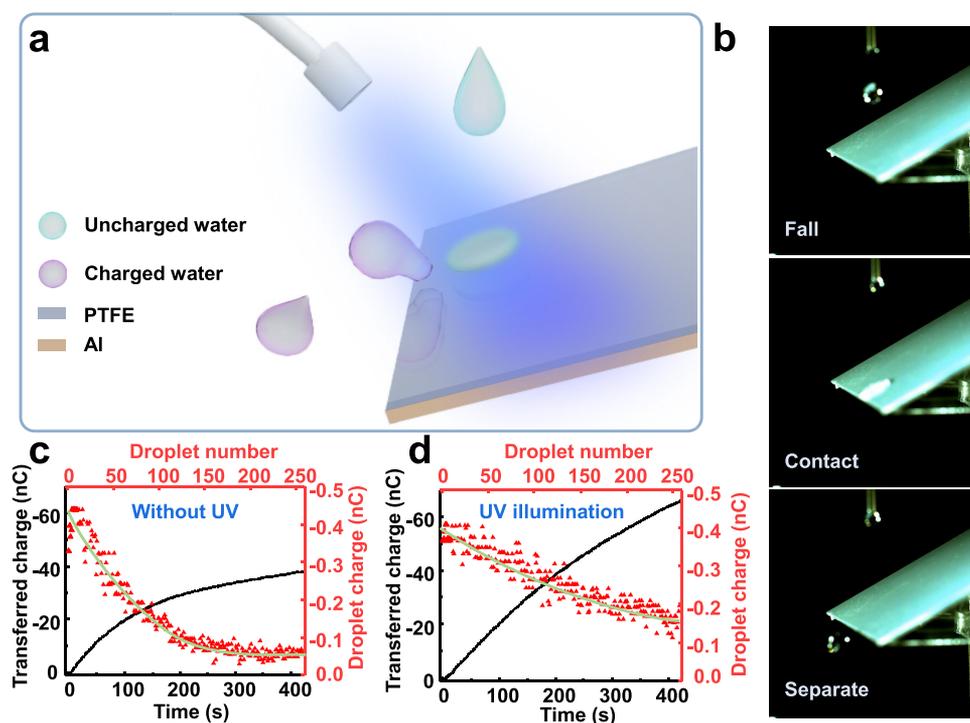


Figure 1. Schematic illustration of experimental method and the effect of UV on CE on the water–PTFE interface. (a) Schematic illustration of the experimental setup. (b) Snapshots of a water droplet falling, contacting, and separating from PTFE. Triboelectric charge of each droplet and transferred charge, tested by a Faraday cup after contact with PTFE, in the dark (c) and under UV illumination (d).

to form OH is revealed.²⁷ On the other hand, the binding mode of water molecules at the L–S interface is distinctly different from that of bulk region and the overlapping of electron cloud between solid and liquid molecules may create some special states, where the reaction barriers as well as the electron-transfer processes can be possibly influenced by the UV light.^{28,29} Thus, further study of the effect of UV on CE at the L–S interface is of great importance for understanding the fundamental physical process at L–S interface.

In this work, we have found that the saturated charge density of L–S TENG can be increased by applying a 365 nm UV light on the electrification surface. The polytetrafluoroethylene (PTFE), fluorinated ethylene propylene (FEP) film, and SiO₂ are selected as the solid electrification materials, while the water droplet is continuously dripped on the solid surface with or without UV. In dark conditions, surface charges saturate quickly with the continuous contact of droplets, while this saturated surface charge density can be further increased by repeating the similar experiments under UV illumination. The UV illumination can cause tiny chemical changes in the PTFE surface, while the generated function groups are supposed to weaken rather than enhance the CE effect. In addition, no attenuation of surface potential is observed under UV, indicating that the photo energy is not enough to release the charges of PTFE surface. Therefore, a photoexcited electron transfer model suggesting that some electron in water can transit and transfer to solid surface with photo auxiliary is proposed to explain UV effect at L–S CE.

RESULTS AND DISCUSSION

CE at the L–S interface is studied by a simple single-electrode TENG as shown in Figure 1a, PTFE and FEP film are selected for contact electrification layer and a smooth aluminum plate covered underneath the electrification layer is the output

electrode, while the TENG surface is fixed with a 30° slope by acrylic support. The surface of PTFE and FEP film is glossy and hydrophobic for droplet contact and separation without residual,³⁰ as shown in Figure S1a,b. Water droplets (50 μL, 18.2 MΩ cm), from a syringe driven by a precision microstepper motor, drop from a grounded needle to the TENG surface and then jump to a Faraday cup with a grounded electrometer to measure the transferred charges of the droplets. The experimental devices are placed in a small glovebox with grounded shell to shield environmental signal (Figure S1d). The initial droplets only have 0.8 pC charge after CE (Figure S1e). The appropriate distance and volume are deliberately designed to ensure effective contact in the same area without rolling or splash, while fluorine-containing polymers ensure that droplets separate without residual water. Figure 1b shows snapshots of the motion behavior of water droplet on the PTFE surface (collision, spread out, and bounce off) (Movie S1 (Supporting Information)). As shown in Figure S1c, when droplets are separated from fluorine-containing polymers, charge transfer occurs at the L–S interface, resulting in the generation of positive charges on droplets and negative charges on the PTFE surface. Meanwhile, positive charges attract the aluminum plate from the ground based on the working principle of TENG.

Transferred charges between droplets and PTFE are collected and measured by Faraday cup and electrometer straightforwardly, as shown in Figure 1c. At the beginning, the transferred charge amount between PTFE surface and each water droplet is around 0.4 nC, where the droplet is positively charged and the PTFE is negatively charged. After continuous electrification at the same position for more than 250 drops, the charge accumulation on PTFE surface gradually increases and tends to saturation. At the same time, the accumulated charge amount in the Faraday cup also gradually reaches the saturation value and the positive charge amount on each droplet gradually

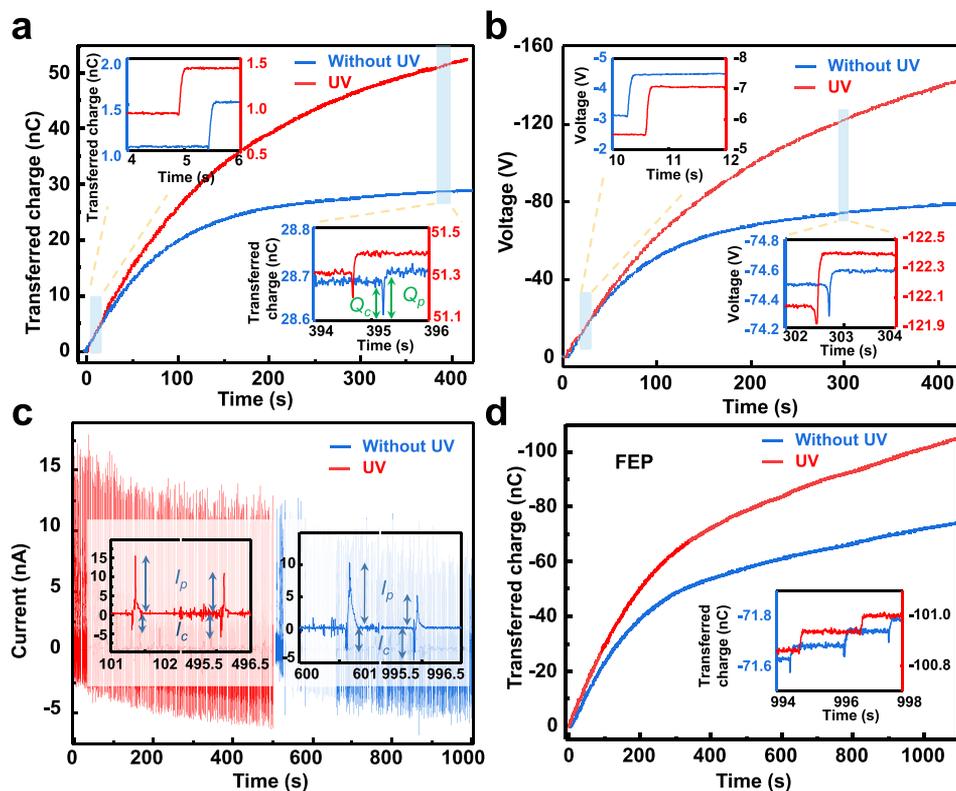


Figure 2. Electricity generation performance of L–S TENG with or without UV irradiation. Transferred charge (a), voltage (b), and current (c) of water–PTFE TENG, in which only the aluminum electrode is connected to a grounded electrometer. (d) Transferred charge of water–FEP CE generated measured by Faraday cup.

decreases to be only 0.08 nC. Under UV light (365 nm), the transferred charge and charge in each droplet are shown in Figure 1d. Here, UV light generated by Lightning Cure LC8 illuminant is aiming at the contact position from a distance of 5 cm, where the light intensity on the targeting surface is almost 120 mW cm^{-1} . Compared with the saturation process in the dark, the charge on each droplet decreases more slowly with UV light, and even after 250 drops of water, the transferred charge amount on each droplet is still around 0.2 nC, indicating that the charge accumulation of on PTFE surface cannot reach saturation under same number of droplets with UV illumination. In other words, UV applied in water–PTFE triboelectrification can enhance charge transfer and elevate saturate charge density.

To further verify UV light's effect on CE at the water–PTFE interface, the single-electrode mode L–S TENG is used as a probe to show the dynamic performance of charge generation on the interface. Transferred charge (Figure 2a), voltage (Figure 2b), and current (Figure 2c) of this L–S TENG are measured by a grounded electrometer. At first, one droplet can generate almost 0.5 nC, 1.5 V, and 15 nA electrical output, almost the same with or without UV light. The contact current I_c and contact charge Q_c (see the inset of Figure 2a,c) are close to zero, while separate current I_p and separate charge Q_p (see the inset of Figure 2a,c) are just effective output current ($I = I_p - I_c$) and effective transferred charge ($Q = Q_p - Q_c$). This result suggests that the original charges on the droplet before it contact with PTFE surface is almost zero and the induced output signal is due to the pure CE effect between droplet and solid surface. With the continuous dripping of droplets, I_c and Q_c gradually increase and the effective output current of TENG decrease slowly with continuous droplet dripping. This attenuate of electrical generation by TENG is due to an increase of the charge density

on the surface of PTFE, which means the active localized states for charge transfer on the PTFE surface is gradually occupied during the repeating contact. Until surface potential of PTFE reach saturation, I_c and Q_c are approximately equal with I_p and Q_p , respectively. Negative charge deposited by 150 droplets on the PTFE surface is sufficient to reach the saturation state without UV illumination, while the effective charge transfer between droplet and PTFE surface is close to zero. After 150 droplets drip in the same area, the effective charge amount induced by each droplet is just 0.02 nC. Under UV light, the charge saturation process is significantly delayed on the PTFE surface and the TENG output can clearly reveal this point. After 250 droplets drip at the same position, the effective transferred charge amount for each droplet is still 0.1 nC and the droplet can generate an output voltage of 0.4 V. It can be clearly noticed in the inset of Figure 2a that Q_p is larger than Q_c . Based on the results in Figure 1c,d and 2a, both the charges of droplets collected in Faraday cup and the electrical output signal from L–S TENG are in good agreement with each other, and the combined results indicate that CE on water–PTFE interface can be enhanced and saturate charge density can be increased due to the existence of UV light.

In addition to PTFE film, FEP and SiO_2 film are also used as a solid triboelectric layer. FEP has higher electronegativity than PTFE, and accordingly, it takes a longer time to reach saturation (Figure 2d). Similar as the case of PTFE, transferred charge of droplets in Faraday cup have a totally different accumulation process with and without UV illumination. The enhancement of UV light on CE occurs at both the water–PTFE interface and water–FEP interface. It should be noted that neither PTFE nor FEP has absorption at 365 nm wavelength as shown in Figure S2a, which means that fluorine-containing polymers we used

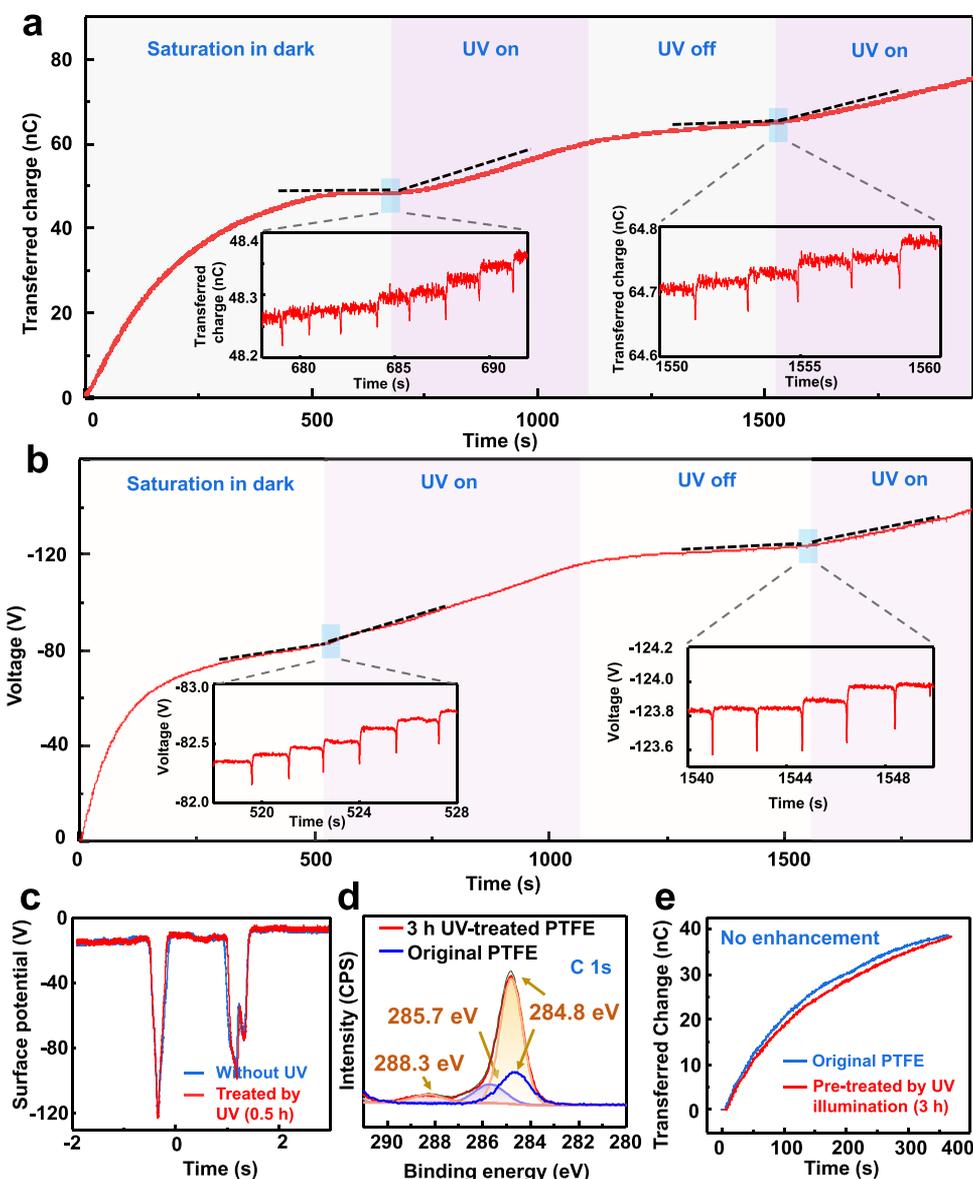


Figure 3. UV effect on water–PTFE contact in different experiment condition and chemical modification of PTFE surface. Transferred charge (a) and voltage (b) of L–S TENG with UV switch on–off cycle. (c) Saturated surface potential of PTFE before and after 30 min UV illumination. (d) High-resolution X-ray photoelectron spectroscopy (XPS) of PTFE C 1s with 3 h UV illumination and original PTFE (the whole spectrum is in Figure S4b). (e) Transferred charge of L–S CE using pretreated PTFE with UV illumination (3 h) and original PTFE, tested by Faraday cup.

here is chemical stable under 365 nm UV illumination. SiO_2 is a kind of inorganic material that is quite stable under the UV illumination, and its electron-withdrawing capability is a little bit stronger than that of water. Hence, SiO_2 film is also selected as the electrification layer for this L–S TENG system in order to verify this photoenhanced CE effect with inorganic materials. It is important to note that the electrification between SiO_2 and water droplets is quite weak, and it is not possible to directly measure the transferred charges. As shown in Figure S2b,c, transferred charge is calculated by using current integration and the current signal under UV light is significantly higher than that without UV. The results shown that enhancement of UV on electrification and saturate charge density not only occurs in fluorine-containing polymers surface, but also occurs on inorganic material surfaces.

On the basis of the results in Figures 1 and 2, it can be confirmed that the UV illumination can effectively enhance the

CE at the L–S interface. However, the underlying mechanism of this enhancement still needs further clarification. Accordingly, the switching test of UV light is also performed with multiple on–off cycles, where the dripping of water droplets is kept at constant mode. At first, the experiment is performed in dark conditions, and the charge accumulation gradually reaches a saturation state, which is the common behavior of L–S TENG. Then the UV light turns on and the transfer charges as well as the output voltage of L–S TENG show a sudden increase (Figure 3a,b). Under UV illumination, the original saturation tendency is stopped, and as shown in the inset, the enhancement of transferred charges instantaneously happens with the appearance of UV light. Meanwhile, when the UV light turns off, the CE behavior on this L–S interface returns to the saturation state. Correspondingly, the charge amount on the droplets, which is collected by a Faraday cup, also increases with the existence of UV light and return to saturation state under dark conditions, as

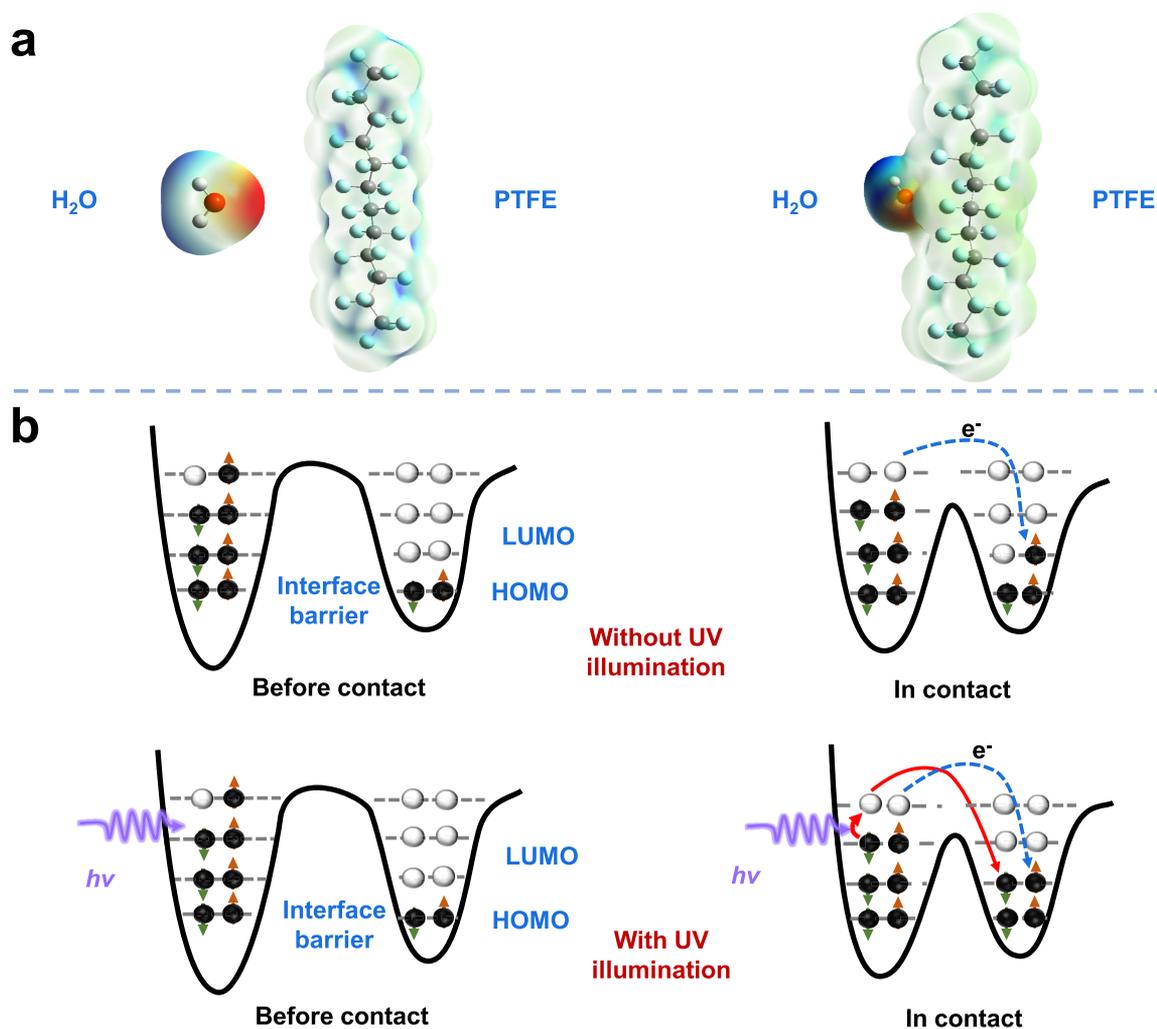


Figure 4. Working mechanism of UV photoexcited contact electrification on water–PTFE interface. (a) Schematic diagram of electron transfer between water and PTFE interface in CE. (b) Electron transfer and photoexcited electron transfer without or with UV illumination in CE based on electron transfer model.

can be seen in Figure S3a. For the current value of TENG, the I_c suddenly decreases and the I_p increases when the UV is turned on, while $I = I_p - I_c$, current have a significant increase (Figure S3b). The similar on–off cycle can be repeated for several times, and the CE process always follows the similar pattern. Meanwhile, it is also necessary to check if the UV light can erase the tribo-induced charges on the PTFE surface. It has been reported that photon with higher energy than a threshold can release the triboelectric charge on dielectric surface.³¹ As shown in Figure 3c, the surface potential of charge-saturated PTFE film showed no significant decay under 0.5 h UV irradiation, indicating that UV light has no effect on surface potential as well as the charge dispersion process on PTFE film. Therefore, it can be deduced that the UV light only influences the charge generation process at the L–S interface and the photo energy of 365 nm UV light is not enough to release the triboelectric charge on the PTFE surface.

Attenuated total reflectance Fourier transform infrared (ATR-FTIR) spectroscopy of 3 h UV-treated PTFE is shown in Figure S3c, and the result suggests that the basic structure of a UV-treated PTFE film is similar as original PTFE. Meanwhile, high-resolution X-ray photoelectron spectroscopy (XPS) data of PTFE (see Figure S4a–d) reveal that tiny modifications of molecular structure of PTFE are induced due to UV illumination

under microscopic surface conditions. The peak in 3 h UV-treated PTFE (C 1s) appears at 288.3 eV, belonging to the –OH group with two adjacent fluorinated carbons (CF₂–CF(OH)–CF₂).³² The peak at 284.8 eV is a carbon type coming from surface contamination, and the peak at 285.7 eV is attributed to branched carbons that may exist in the cross-link network after the treatment (see Figure 3d and Figure S4b). The result indicates that chemical defluorination reaction happens under 3 h UV irradiation, where fluorine atoms are taken off and OH groups form. XPS of O 1s and F 1s is shown in Figure S4c,d, where a peak of O 1s at 531.1 eV may be –OH produced by UV irradiation. However, on the basis of previous study,¹⁹ the change from the F group to the OH group leads to a decrease of electron-withdrawing capability, which is actually a negative effect for the electrification in this case. More importantly, a UV-treated PTFE (3 h) is put back to the TENG system and a similar experiment with L–S CE is performed with continuous dripping droplets. Finally, the saturated value of transferred charge amount shows a little decrease in comparison with original film, as shown in Figure 3e. Moreover, as can be seen in Figure 2a, the enhancement of L–S CE can happen immediately with the appearance of UV light, and this short time is not enough to trigger defluorination reaction. Hence, the chemical modification under UV illumination is not the reason for this

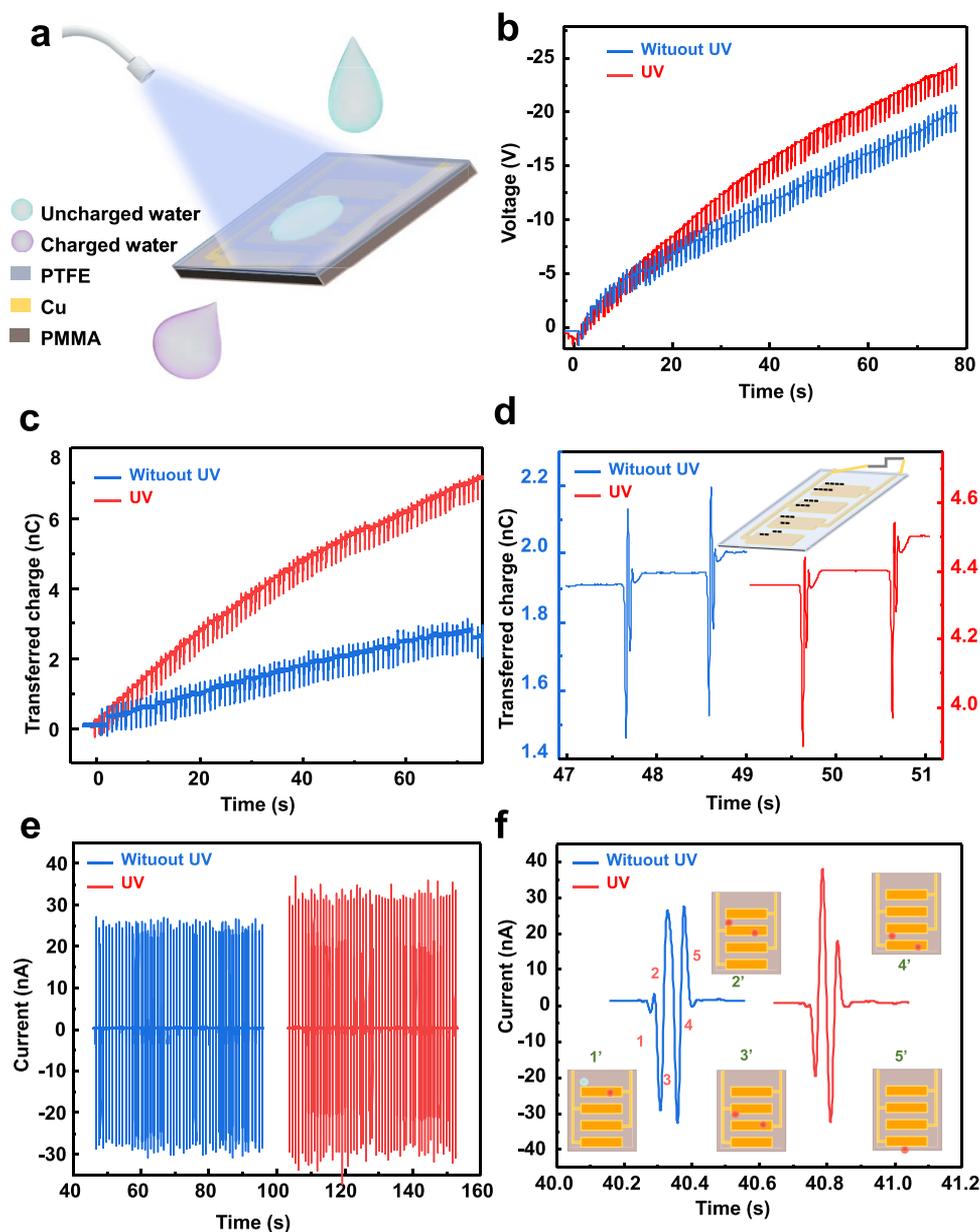


Figure 5. UV effect on water–PTFE CE tested by freestanding model liquid-TENG with grafting electrode as probe. (a) Schematic illustration of the grafting-TENG. Voltage (b), transferred charge (c), and current (e) of grafting-TENG with or without UV, tested by TENG as “probe”. (d) Single current signal generated by one drop with droplet motion in insert. (f) Amplified curve of transferred charge (d).

enhanced L–S CE effect, and we need to focus on the electron transfer process happen on the L–S interface in order to clearly explain this effect.

According to the Wang’s electron transfer model for L–S CE,^{2,31–35} the liquid molecules collide with atoms of solid surface under the drive of liquid pressure, while this collision may lead to the overlap of electron clouds. The overlap of electron clouds raises the possibility for electron transfer between water molecules and solid atoms. In our experiments, electrons are transferred from water molecules to fluorine-containing polymers with strong electron electronegativity, and this electron-transfer process is related to the hopping of electrons from a high energy state to a low energy state. Meanwhile, the transferred charges also change the electronics structure of solid atoms, leading to the enlarged electron cloud range,¹⁹ which gradually decrease the electron-withdrawing capability of the solid surface. Then, if a large number of surface

states on solid surface are occupied and the electron-withdrawing capability of solid surface is comparable with the water molecule, the charge transfer process may reach saturation state. However, if UV illumination is applied on the water molecule, electrons can be excited to higher energy state. Accordingly, the electron-withdrawing capability of solid surface at saturation state is still enough to further capture electrons from water molecule and the saturated charge density can be further increased. Therefore, a photon-excited electron transfer model based on the Wang’s electron transfer model is proposed to explain the effect of UV on CE at the L–S interface, as can be seen in Figure 4a,b. Figure 4a is three dimensionally electrostatic potential maps of $C_{12}F_{26}$ (simulating PTFE), and H_2O and the overlapped electron clouds are calculated by the density functional theory (DFT) method. The blue regions are positive potentials with electron-poor regions and red regions are negative potentials with electron-rich regions. Obviously, when

water contacts PTFE, the electron-rich regions in O of H₂O prefer to overlap with electron-poor regions of the PTFE. Meanwhile, photoexcited electron transfer model is shown in Figure 4b, which illustrates the electron transfer at L–S interface without or with UV illumination. It is shown that some electrons of water molecular, which cannot transfer to PTFE surface under normal conditions, can be excited to higher energy state and then transfer to PTFE surface.

It is important to note that the bulk water has no absorption of UV at 365 nm (Figure S5). However, we believe it is not contrary to our conclusion. The aggregation mode of water molecules at the L–S interface is different from that in the bulk region and the overlapping of electron cloud between solid and liquid molecules is also a special transient state, which may have some unusual interaction with UV light. On the other hand, there is a small probability that the electron-transfer process happened on the contacted interface, while only a few molecules can reach the correct state of electron cloud overlap for electrons transfer. When the UV light is applied on the saturated L–S interface, the transferred charge amount for each droplet increases from 0.08 to 0.2 nC ($1.25 \times 10^9 e^-$). The contact area between the droplet and PTFE is about 1 cm², and the droplet volume is 50 μL, so there are at least 6.7×10^{17} water molecules participating in the CE process at the L–S interface. Thus, the probability of photoexcited electron transfer is only 0.2×10^{-8} for the water molecules at L–S interface, which should be smaller than the detecting limit of common absorption spectra measurements. To further explain the photo excitation on L–S interface, band theory is also demonstrated in Figure S6 and Supporting Note 1. The photo energy of UV light used here should be just enough to excite some electron in states to transfer into PTFE surface and not enough to excite the electron in surface states to transfer back. Thus, the electron of water in the L–S interface is excited to promote electron transfer and improve saturate charge density.

A grafting Cu electrode is used to replace Al plate, and a different device structure is established for studying the effect of UV light on freestanding L–S TENG. As shown in Figure 5a, a simplified grafting electrode on PMMA plate is covered by PTFE film, and droplets drip on the top of devices and slide across the grafting electrode. A schematic diagram and photograph of grafting electrode are shown in Figure S7a. Grafting TENG, as an energy package or a sensor device, has potential applications for microfluidic detection and energy harvesting. Voltage (Figure 5b) and transferred charges (Figure 5c) of the freestanding L–S TENG also show a small increase under UV illumination. Moreover, the surface potential difference caused by the order of droplets contact with the PTFE surface can be observed in Figure 5d. The droplet slide over the second grid, already positively charged on first grid, can transfer less charge than first grid. Thus, transferred charges of droplets decrease progressively with the order of passing through the electrodes, and the surface potential of PTFE also shows a difference between grids, suggesting that output transferred charges and voltage have steps between successive droplets. The current of grafting TENG is 25 and 35 nA without or with UV lighting, respectively (Figure 5e). Interestingly, current shape can reflect speed and position of sliding droplets, which can be used to microfluidic sensing and control. When a droplet contacts with PTFE on the first grid, electrons flow to the electrode and create a negative current (Figure 5f). Then the droplet leaves the first grid until it completely contacts with PTFE on the second grid, and electrons flow from the first grid

to the second and positive current is generated. Similarly, when a droplet leaves the second grid and completely contacts with PTFE on the third grid, a negative current is created. When it leaves the third grid to completely contact with PTFE on fourth grid, a positive current is generated. At last, droplets past the fourth grid and negative current goes back to zero. The charging performance of the grating TENG to a 0.1 μF capacitor is shown in Figure S7b, and 100 s can charge the capacitor to 0.8 and 1.0 V without or with UV, respectively. The output performance of L–S TENG and difference of the surface potential and charge capacitor performance is enhanced under UV light, which can be a strategy to improve energy harvesting and motion sensor of droplet.

CONCLUSIONS

In summary, we found that saturation charge density on PTFE surface during L–S CE can be further enhanced by UV illumination of 365 nm. A series of experiments have been done to identify the origin of this photoinduced enhancement and various factors have been ruled out, including anion generation, chemical change of solid surface, ionization of water, and so on. Finally, the mechanism of this UV-enhanced CE effect is believed to be the photoexcited electron transfer at L–S interface, which can be well explained based on Wang's electron transfer model. We have several evidence to support this conclusion:

1. The saturated charge density at L–S interface is enhanced, which means that the interaction between droplets and PTFE surface is strengthened. On the basis of previous studies, it should be either an electron transfer or ion adsorption process being enhanced by UV light.
2. Similar experiments have been performed in open air and argon atmosphere, which rule out the possibility of oxygen anion generation. Both PTFE, FEP and bulk water have no obvious light absorbance at 365 nm, and ionized reaction cannot be induced under this UV light. Moreover, even if UV light can increase the ion concentration in the droplet, this cannot explain the enhance CE effect, since the increase of ion concentration usually leads to the suppression of CE.⁴
3. Chemical modification on a solid surface usually can enhance ion adsorption on the surface. However, chemical defluorination and –OH formation on PTFE surface need a rather long time, while the charge amount of L–S CE immediately increases with the appearance of UV light. Meanwhile, the L–S CE on the PTFE, which is pretreated by UV illumination for 3 h, shows no enhancement. Hence, the chemical change on solid surface is not the origin of this enhancement, which further rules out the possibility of ion adsorption.
4. The surface potential of charge-saturated PTFE film show no significant decay under UV irradiation for 0.5 h, indicating that the photo energy is smaller than the threshold to release the triboelectric charges of PTFE surface. Therefore, it is the L–S interface rather than bare solid surface being excited by UV light.

Thus, a photoexcited electron-transfer model is proposed to explain the enhanced CE under the UV illumination. Under UV illumination, electrons of water molecule can be excited to higher energy state and thus, the solid surface at saturation state still have enough electron-withdrawing capability to further capture electrons from water molecule. According to previous

study,²¹ the band gap of water is determined to be 6.9 eV, which is much larger than photon energy of applied UV light (365 nm). However, the CE-induced charge transfer usually happens with the localized surface state in the band gap,^{32,33} and it is possible that the excitation of these surface state can happen under the UV light.

In addition to single-electrode TENG, a free-standing TENG with grating electrodes is also designed to demonstrate the enhancement provided by UV light, indicating great application perspective of this method for energy harvesting and microfluidic sensor. Hence, this work not only further clarifies the mechanism of CE at L–S interface, but also provides another approach to boost the performance of L–S type TENG, which can be a guidance for the study of microfluidic sensors, droplet energy harvesting, droplet manipulation, and so on.

METHODS

Fabrication of TENG. The PTFE film used here is ASF-110 FR (50 μm) bought from Chukoh Company (Japan) and FEP film (30 μm). In single electrode TENG, PTFE films are carefully attached onto smooth aluminum plate films with a thickness of 2 mm, and ethanol pretreated and dry, heat in a vacuum oven at 80 °C to remove surface residual charge before experiment. Note that the adhered PTFE films must cover all aluminum plate to avoid the electrical interference from droplets to electrode and avoid the chemical corrosion in solutions. Grafting electrode TENG is four 3 \times 20 mm copper electrode by 10 min magnetron sputtering with 2 mm distance on PMMA plate under PTFE film, first grid connected third grid to form one electrode and second, fourth grid form the other electrode.

Characterization. The electrical signals of TENG were determined by a Keithley 6514 System Electrometer. Transferred charge of droplets were collected by a Faraday cup and a grounded 6514 electrometer. The surface potential was measured with a TREK 347 electrostatic voltmeter. The surface morphology of the materials was observed using a Nova NanoSEM 450 field emission scanning electron microscopy. Their structure was obtained by a Fourier transform infrared spectrophotometer (VERTEX80v) and high-resolution X-ray photoelectron spectroscopy (ESCALAB250Xi). The contact angle came from a contact angle measuring machine (CA100C).

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at <https://pubs.acs.org/doi/10.1021/acsnano.1c03358>.

Experimental results of SEM of films, working principle, photo of experiment setup, output of water–SiO₂ CE, voltage and current of L–S TENG, XPS and UV spectrum, photoexcited electron transfer model and explains, grating-TENG structure, and performance of charging capacity (PDF)

Motion behavior of water droplet on PTFE surface (MP4)

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Author Contributions

*X.T. and J.N. contributed equally to this work. X.C. and Z.L.W. conceived and lead this project. X.T. and J.N. performed all of the experiments. S.L. and Y.S. helped with the data analysis. S.L. helped with analysis of the experimental results. All the authors contributed to the preparation of the manuscript and revisions of this work.

Funding

This work was supported by the National Key R & D Project from Minister of Science and Technology (2016YFA0202704), the National Natural Science Foundation of China (Grant No. 51775049), Beijing Natural Science Foundation (4192069), the Beijing Municipal Science & Technology Commission (Z171100000317001), Young Top-Notch Talents Program of Beijing Excellent Talents Funding (2017000021223ZK03), Beijing Nova program (Z201100006820063), and Youth Innovation Promotion Association CAS (2021165).

Notes

The authors declare no competing financial interest.

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