Electronic Supplementary Material (ESI) for Nanoscale.

Supporting Information

Wavy-shaped hybrid piezoelectric and triboelectric nanogenerator based on P(VDF-TrFE) nanofibers

Xuexian Chen,[a] Mengdi Han,[b] Haotian Chen,[a] Xiaoliang Cheng,[b] Yu Song,[b] Zongming Su,[b] Yonggang Jiang,[c] and Haixia Zhang*[a,b]

[a] Academy for Advanced Interdisciplinary Studies, Peking University, Beijing 100871, China

[b] National Key Lab of Micro/Nano Fabrication Technology, Peking University, Beijing 100871, China

[c] School of Mechanical Engineering and Automation, Beihang University, Beijing 100191, China

* Corresponding author: Haixia (Alice) Zhang, Tel: +86-10-62761789, Email: zhang-alice@pku.edu.cn

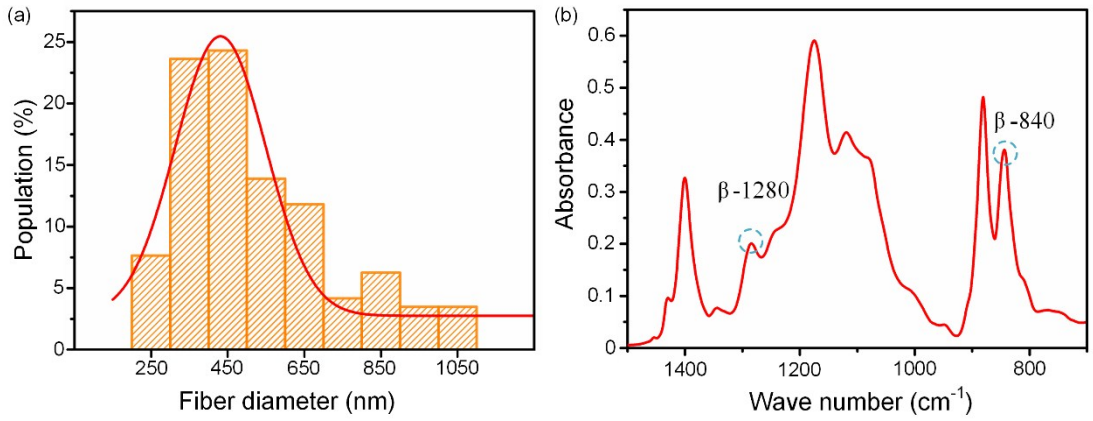

Figure S1 (a) Typical fiber diameter distribution and fit by a Gaussian curve. (b) Fourier transform infrared (FTIR) spectra of the P(VDF-TrFE) nanofibers. The absorbance peaks appear distinctively at 840 cm^{-1} and 1280 cm^{-1}, corresponding to the β phase of P(VDF-TrFE), which is important for the piezoelectric output.

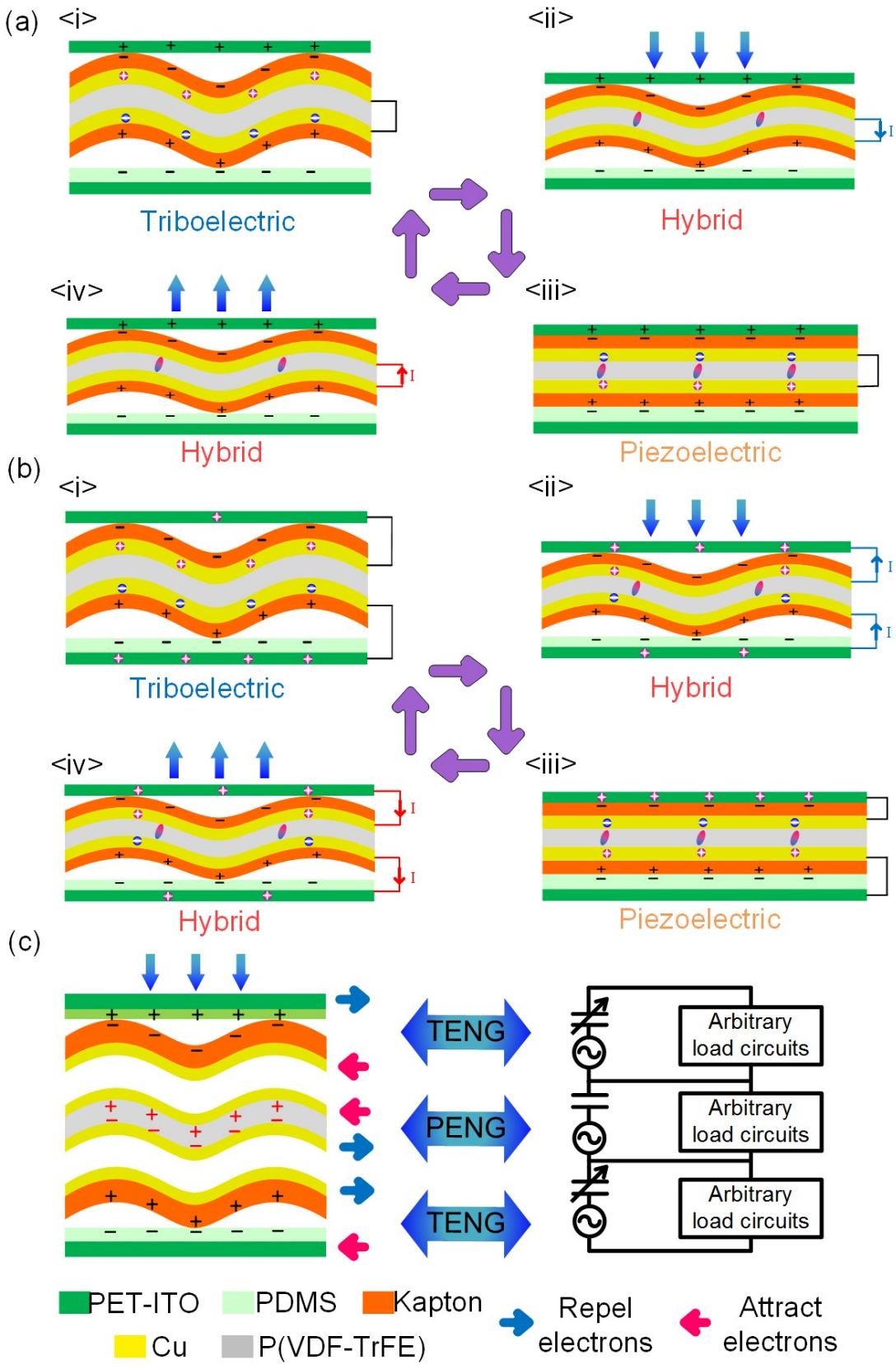

Figure S2 (a) Working principle of the hybrid NG when the triboelectric charges enhance the output of PENG. (b) Working principle of the hybrid NG when the

piezoelectric potential enhances the output of TENGs. (c) The charge transfer situation under pressing state and interface circuit of the hybrid device.

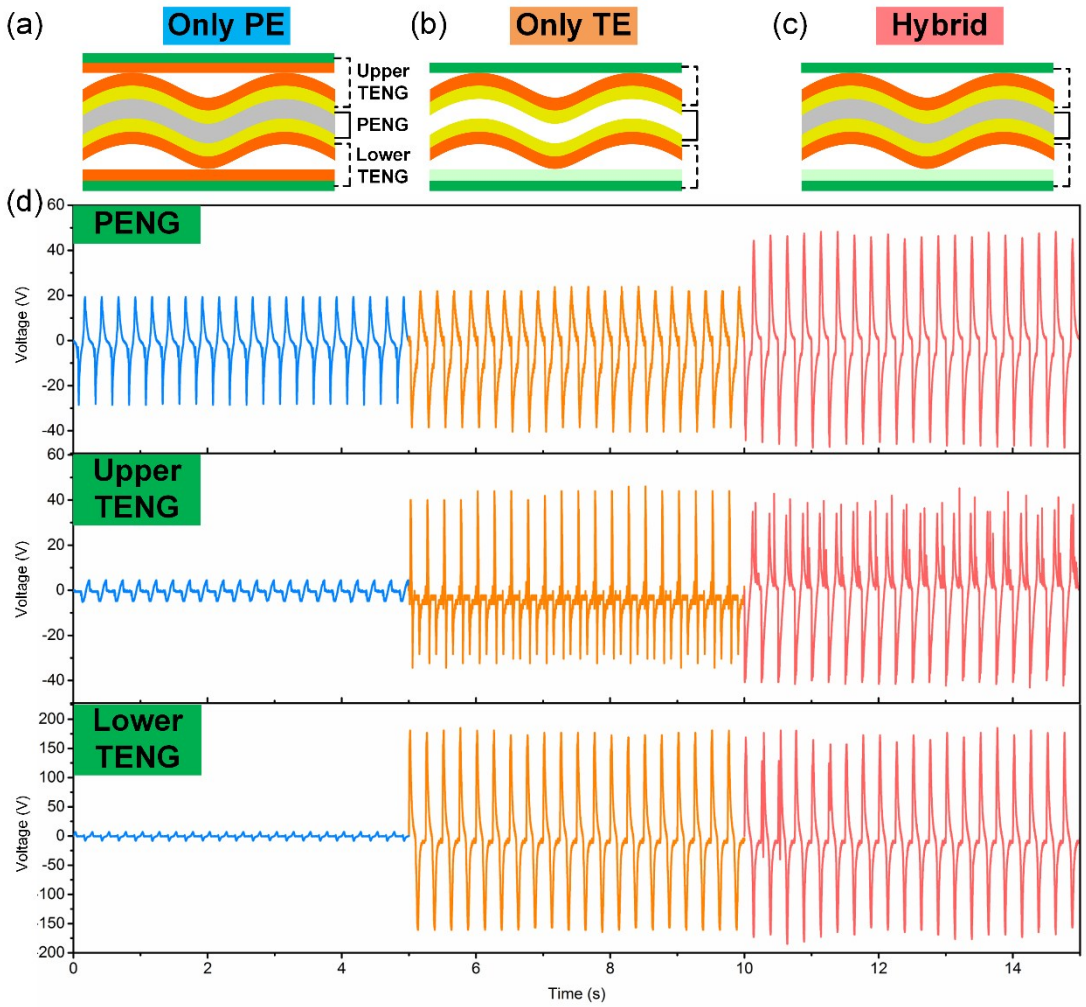

Figure S3 Different test situations for verification of the simulation results. (a) the only PE mode (replace all the friction layers with Kapton film to avoid triboelectric charges), (b) the only TE mode (replace the P(VDF-TrFE) nanofibers with paper) and (c) the hybrid mode. (d) the output signal waveforms for each NG in the three test situations. The blue line represents the "only PE" mode, the orange line represents the "only TE" mode and the red line represents the "hybrid" mode.

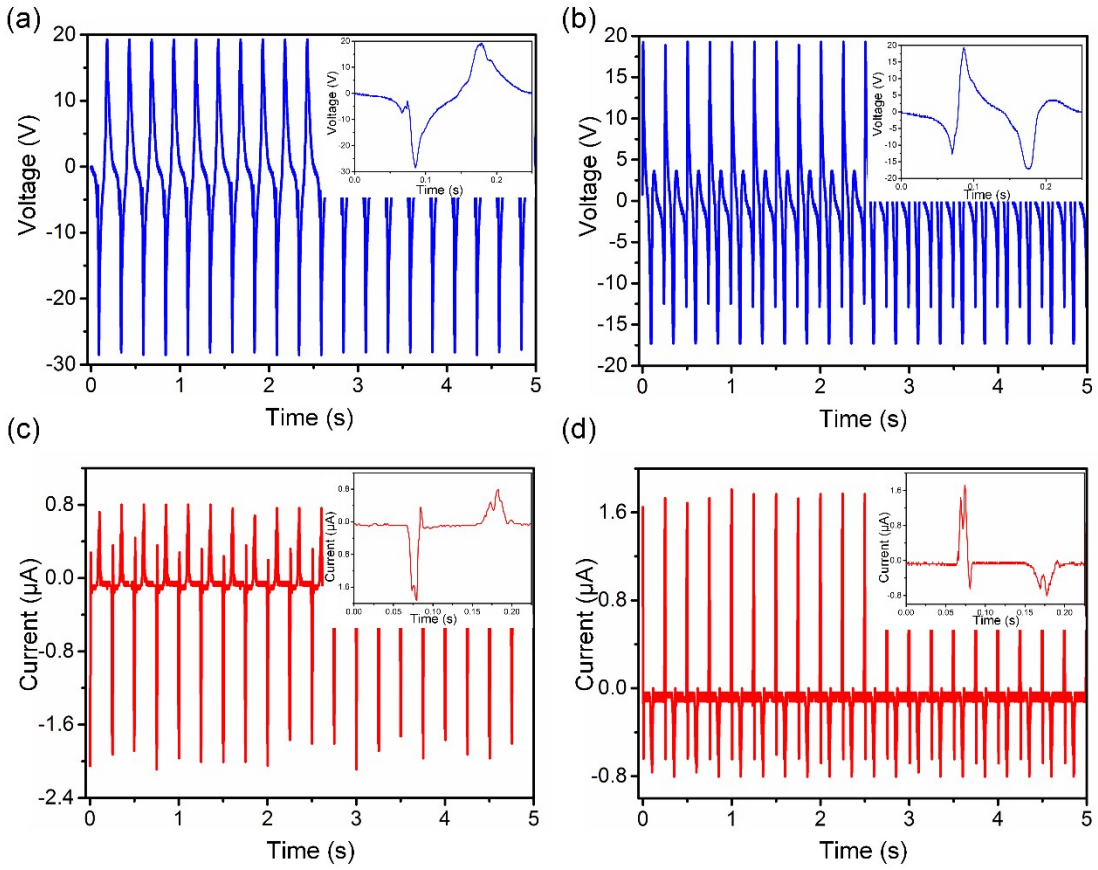

Figure S4 Output voltage of the piezoelectric film with forward (a) and inverse (b) connection. Output Current of the piezoelectric film with forward (c) and inverse (d) connection. The insets show enlarged curves of each output in one cycle. The generated waveforms inversed as the changes of the connection, which confirms that the output of the nanofibers is derived from the piezoelectric effect other than the electrostatic induction of the electrodes or the triboelectric effect.

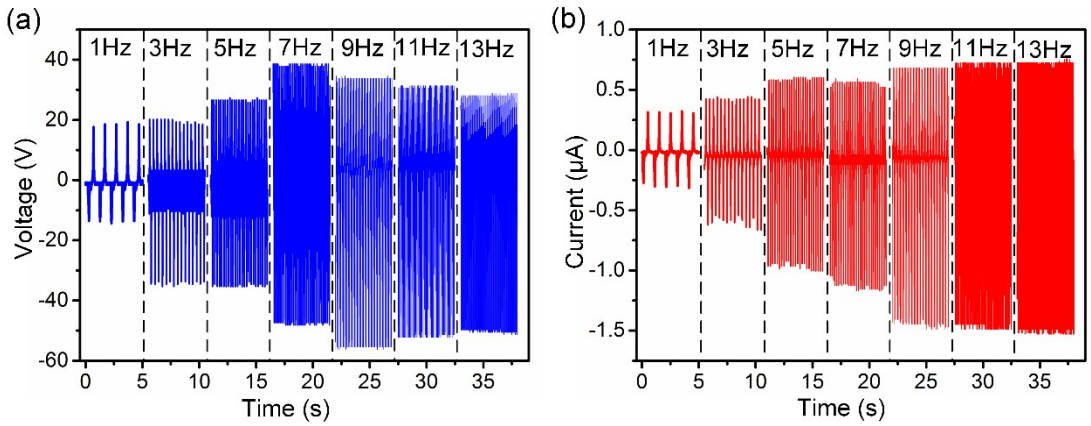

Figure S5 (a) Output voltage (b) and current of PENG under different frequency external forces.

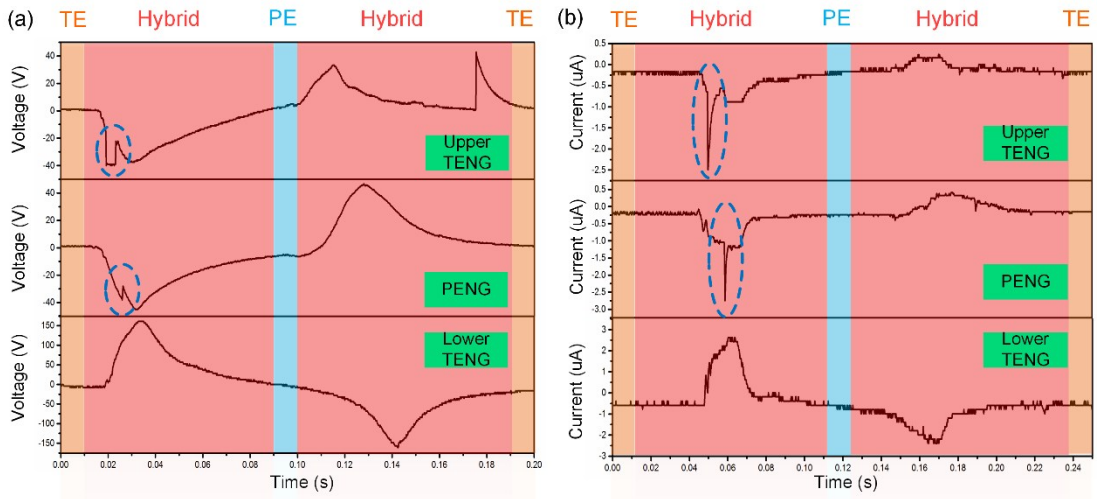

Figure S6 One single cycle of measured voltage (a) and current (b) signals of these three generators in one press and release cycle.

At first, the positive and negative triboelectric charges are separated and no piezoelectric potential is generated for the charges are in an equilibrium state, corresponding to the "triboelectric" state in Fig. 2b; After being pressed, the potential difference generated by the triboelectric charges diminished while the piezoelectric potential getting stronger, driving electrons flow between the four electrodes and thus generating outputs. This is the "hybrid" state as shown in Fig. 2c; When the device is fully compressed, the center of the positive and negative charges on the friction layers coincide while the piezoelectric potential become biggest. The potential comes to a new equilibrium state, so no outputs are generated. For there is only piezoelectric potential at this moment, we called it "piezoelectric" state as shown in Fig. 2d; When the force is released, the effect of piezoelectric and triboelectric will work again and the device will generate reversed output under the work of hybrid effect (Fig. 2e). After the device is fully released, it recovers to the initial state again.

For the short-circuit current, charges would transfer in a quite short time, therefore, the pulse width of the current is much smaller than that of voltage. The "TE" and "PE" state are transition status, all the outputs are generated during the hybrid state, that is, the output of the PENG is influenced by the triboelectric charges and vice versa. For example, the current waveform of the upper TENG is very sharp, which also reflects in the current waveform of the PENG.