The space tribo-charge region and equivalent charge plane model in triboelectric nanogenerators

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Note S1. Derivation of typical average distance among triboelectric charges

Note the surface charge density as σ. The amount of charge carried by a single elementary charge is $e = 1.6\times10^{-19} C$. The number of carriers N in a unit area can be expressed as:

$$N = \frac{\sigma}{e} . \qquad \text{* MERGEFORMAT (S1)}$$

The average area A occupied by a single carrier is:

$$A = \frac{1}{N} = \frac{e}{\sigma} . \qquad \text{* MERGEFORMAT (S2)}$$

Assuming the shape of area occupied by each charge carrier is a circle with the charge located at its center, radius of the circle r is:

$$r = \sqrt{\frac{2A}{\pi}} = \sqrt{\frac{2e}{\pi\sigma}} . \qquad \text{* MERGEFORMAT (S3)}$$

For $\sigma = 1\times10^{-3} C/m^2$, r is about 10 nm.
For $\sigma = 1\times10^{-9} C/m^2$, r is about 10 μm.

The average distance between two charge carriers is considered to be $2r$. As derived above, the magnitude of the distance between each charge carrier is approximately 20 nm to 20 μm. This derivation emphasizes the fact that only when observation point is sufficiently far away from triboelectric charge can we treat them like uniformly charged plane. When observed at a close range, especially at a distance comparable to the average separation between triboelectric charges, these charges behave more like point charges rather than uniformly charged planes.

Note S2. Simulation of electrostatic potential distribution of randomly distributed charges and equivalent charge plane

a) randomly distributed charges

Ten elementary point charges were placed within the space tribo-charge region, with their positions in the xy-plane randomly chosen within a 100 nm×100 nm area. The buried depth of charges beneath contact surface was also random within 1 nm to 10 nm, while average distance from point charges to the contact surface was controlled to be 5 nm. Electrostatic potential distributions for dielectric layer thicknesses ranging from 10 nm to 200 nm, with each increment of 10 nm, are shown in Fig. S1 a-t. Potential of the contact surface (the square surface located at the right side of the cuboid) is set to be 0 as the boundary of this simulation.

b) equivalent charge plane

A charge plane of dimensions 100 nm × 100 nm was placed 5 nm away from the contact surface. The surface charge density was set to be equal to that of the randomly distributed charges in the previous simulation. Electrostatic potential distributions for dielectric layer thicknesses ranging from 10 nm to 200 nm, with each increment of 10 nm, are shown in Fig. S2 a-t. Potential of the contact surface (the square surface located at the right side of the cuboid) is set to be 0 as the boundary of this simulation.

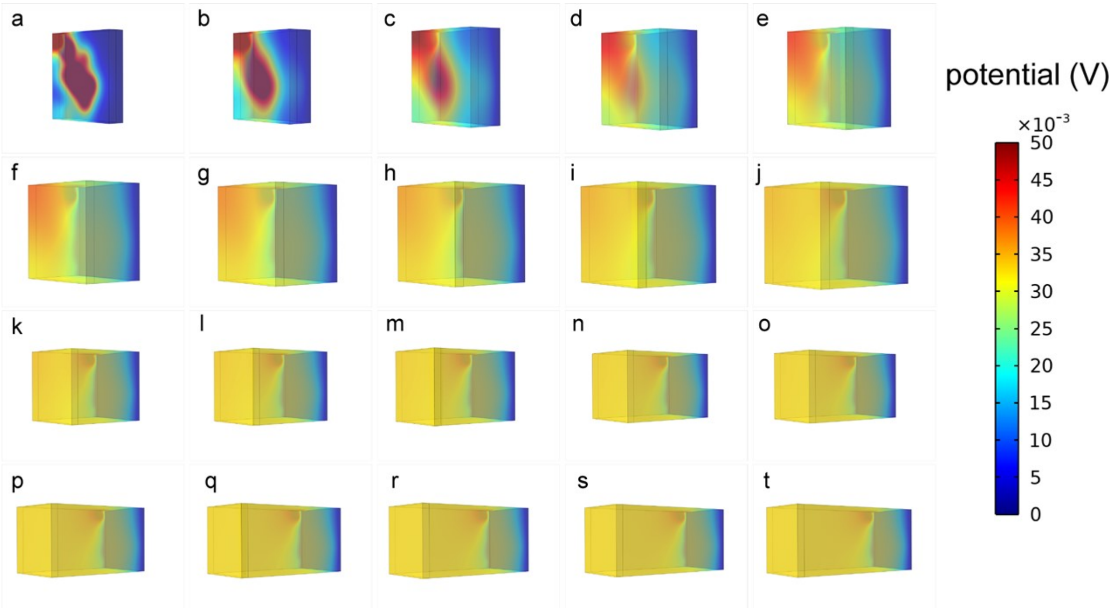

Figure S1. Simulation of electrostatic potential distributions of randomly distributed electric charges. a-t) Simulation of dielectric layer thickness from 10 nm to 200 nm, with each increment of 10 nm.

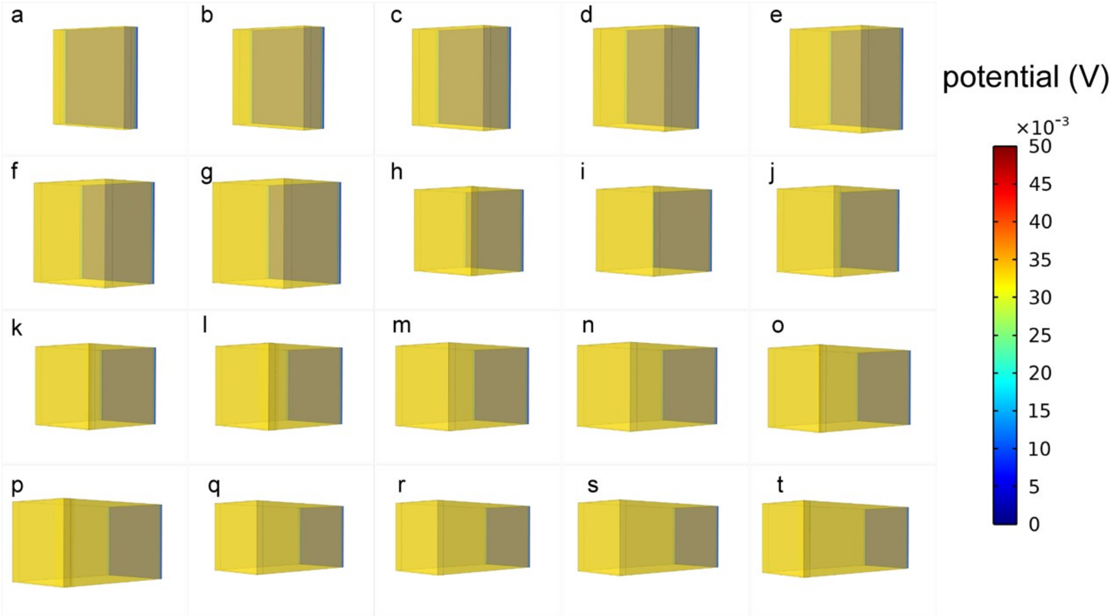

Figure S2. a-t) Simulation of dielectric layer thickness from 10 nm to 200 nm, with each increment of 10 nm.

Note S3. Short circuit current (I_{sc}) of TENGs with varied thickness in FEP layers

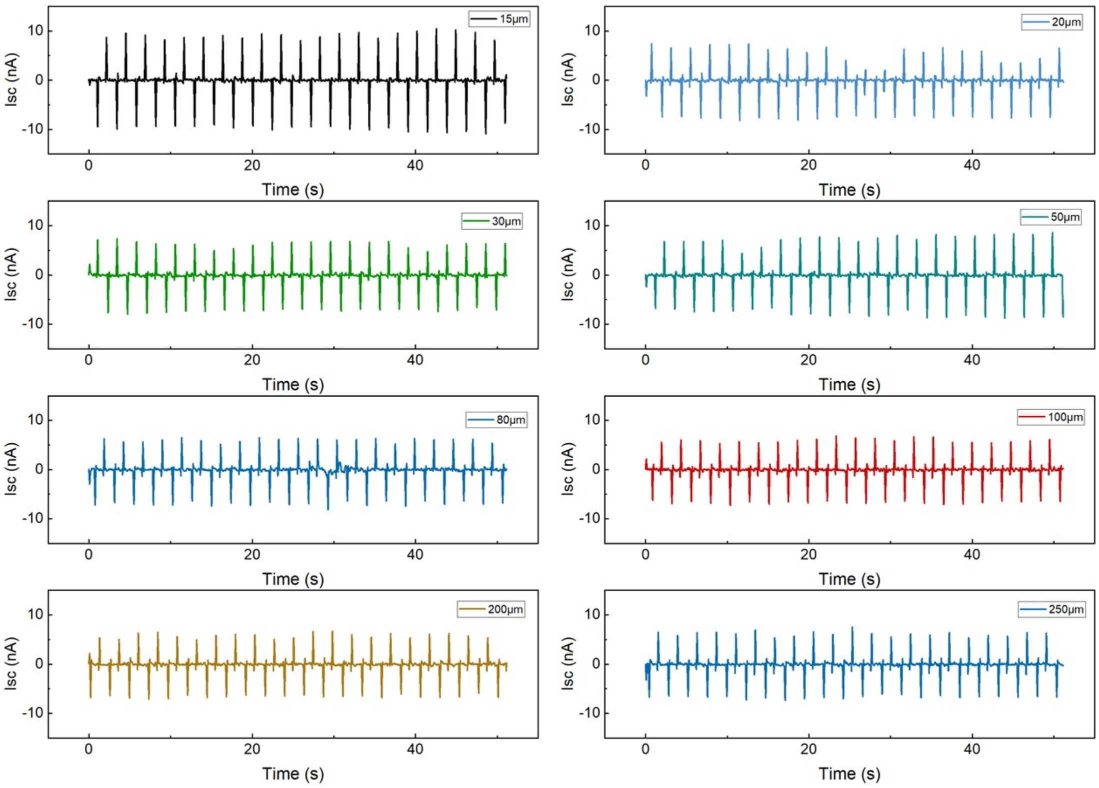

Figure S3. Short-circuit current I_{sc} vs. time plots of TENGs with PDMS layer fixed at 500 μm and varying FEP thickness. FEP thicknesses are labeled in legends of corresponding graph.

Note S4. Open circuit voltage output (V_{OC}) of TENGs with varied thickness combinations of FEP and PDMS layer

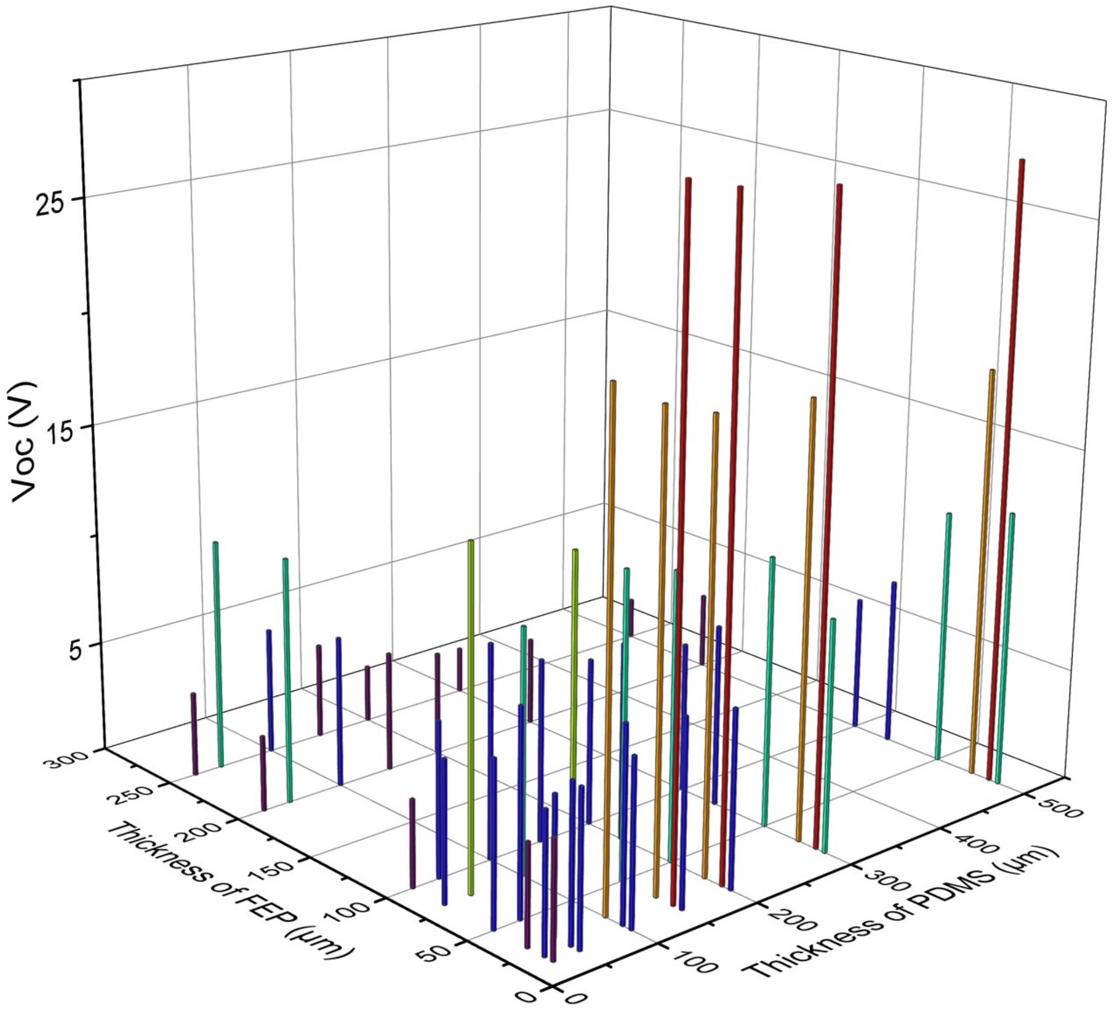

Figure S4. Relationship between PDMS and FEP layer's thickness combinations and open circuit output voltage.

Note S5. Table of symbols used in derivation of Electric field and potential produced by charges inside STCR

Symbol	Meaning
E_{ind}	Electric field induced by a single charge
k	Coulomb constant
e	Amount of charge carried by an elementary charge
r, r_1, r_2	Distance from contact surface (r_1, r_2 corresponding to positions inside dielectric layer 1 and 2)
h	Buried depth beneath contact surface
E_1, E_2	Absolute values of the induced electrostatic fields within dielectric layer 1 and 2
ρ	Charge density of ECP
ε_0	Permittivity of vacuum
ε_1, ε_2	Permittivity of dielectric layer 1 and 2
d_1, d_2	Thickness of the STCRs in dielectric layer 1 and 2
V_1, V_2	voltage shifts between contact surface and the border of dielectric layers in contact stage
t_1, t_2	Thickness of dielectric layer 1 and 2
V_{c}	Voltage between two electrodes at contact stage
d_{g}	Length of the air gap between two dielectric layers in separation stage
E_{g}	Electric field intensity at any point inside the air gap
l	Distance of any point inside the air gap from contact surface
V_{pg}	Potential of the positively charged STCR in separation stage
V_{ng}	Potential of the negatively charged STCR in separation stage
V_{pd}	Absolute value of potential difference from the positively charged STCR boundary to the conductive electrode
V_{nd}	Absolute value of potential difference from the negatively charged STCR boundary to the conductive electrode
V_{s}	Voltage between two electrodes at separation stage
V_{oc}	Open circuit voltage output of each contact-separation cycle