Reverse electrowetting as a new approach to high-power energy harvesting

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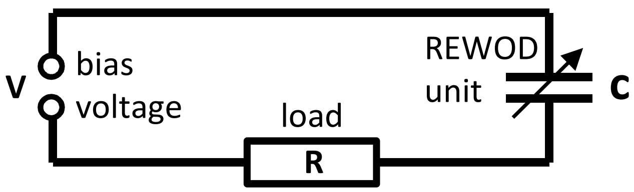

Supplementary Figure S1: Schematics of the electric circuit used to investigate energy generation.

Supplementary Methods

The electric circuit used to investigate energy generation was identical for all three actuation methods. The circuit is shown in Supplementary Figure S1 and includes a source of a bias voltage *V*, a resistive load *R*, and a variable capacitor *C* (the REWOD unit), which represents a harvester setup, i.e. a set of droplets in contact with the electrode grid. The voltage drop on the resistive load was captured by the data acquisition board and converted into electrical current allowing direct calculation of the generated power as a function of time.

The behavior of the electrical circuit shown in Supplementary Figure S1 can be theoretically described using the following equation:

$$\frac{dQ}{dt} + \frac{Q}{RC} - \frac{V}{R} = 0$$
$$Q(t=0) = VC_0 \qquad \text{(S1)}$$

Where Q is the charge on the variable capacitor, *R* is the load impedance, *C* is the capacitance of the variable capacitor, C_0 is the maximum capacitance of the variable capacitor, *V* is the bias voltage, and *t* is time. Variation of capacitance with time can be approximated as:

$$C(t) = \tfrac{1}{2} C_0 \left(1 + \cos(\omega t)\right)$$
$$C_0 = \varepsilon_0 k A h^{-1} \qquad \text{(S2)}$$

Where *A* is the maximum overlap area between the droplets and the electrodes achieved during the wetting-dewetting cycle, *h* is the thin film dielectric thickness, *k* is the thin film dielectric constant, ε_0 is vacuum permittivity, and $\omega = 2\pi T^{-1}$ is capacitance oscillation frequency , where T is characteristic period of one wetting-dewetting cycle.

Eq. (S1) can be rewritten in dimensionless form:

$$a\frac{d\hat{Q}}{d\hat{t}} + \frac{2\hat{Q}}{1+\cos\hat{t}} - 1 = 0$$
$$\hat{Q}(\hat{t}=0) = 1 \tag{S3}$$

Where $\hat{Q} = QV_0^{-1}C_0^{-1}$, $a = \omega RC_0$, and $\hat{t} = \omega t$. The solution of Eq. (S3) takes the form:

$$\hat{Q} = \frac{1}{a} e^{-\frac{2i}{a} - \frac{2\mathrm{Tanh}\left[\frac{t}{2}\right]}{a}} \left(a e^{\frac{2i}{a}} + i e^{\frac{4i}{a}} \mathrm{Ei}\left[-\frac{2i}{a}\right] - i\,\mathrm{Ei}\left[\frac{2i}{a}\right] - i e^{\frac{4i}{a}} \mathrm{Ei}\left[\frac{2\left(-i + \mathrm{Tanh}\left[\frac{t}{2}\right]\right)}{a}\right] + i\,\mathrm{Ei}\left[\frac{2\left(i + \mathrm{Tanh}\left[\frac{t}{2}\right]\right)}{a}\right] \right)$$

Where Ei is exponential integral, Tanh is hyperbolic tangent, and i is imaginary unit. The energy generated per one wetting-dewetting cycle can be expressed as

$$\hat{E} = \int_{\mathrm{period}} a\left(\frac{d\hat{Q}}{d\hat{t}}\right)^2 d\hat{t} \tag{S4}$$

where the integral is taken over one oscillation period. The integral in Eq. (S4) can be approximated as

$$\hat{E} = \tfrac{5}{4}\left[1 - \mathrm{Tanh}\left(\tfrac{1}{2}\left(1 - \mathrm{Log(a)}\right)\right)\right] \tag{S5}$$

The Eq. (S5) can be rewritten in original variables as:

$$E = \tfrac{5}{4}V^2 C_0\left[1 - \mathrm{Tanh}\left(\tfrac{1}{2}\left(1 - \mathrm{Log}\left(\omega RC_0\right)\right)\right)\right] \tag{S6}$$

Thus, the average generated power can be presented as

$$P = \tfrac{5}{4}V^2 C_0 T^{-1}\left[1 - \mathrm{Tanh}\left(\tfrac{1}{2}\left(1 - \mathrm{Log}\left(\omega RC_0\right)\right)\right)\right] \tag{S7}$$

The theoretical curve described by Eq. (S5) is plotted in Fig. 3(a) in the main text as a solid line. One can see that the shape of this curve is similar to the experimental curves shown in Fig. 2(e). In order to quantitatively compare theoretical predictions with the experimental data, the results for the average energy density per one wetting-dewetting cycle presented in Figs. 2(a) and 2(d) are re-plotted in Fig. 3(a). Both the channel setup data and the sliding plates setup data collapse onto the same theoretical curve, supporting the validity of the model.