Supplementary materials

New pyroelectric figures of merit for harvesting dynamic temperature fluctuations

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We now derive example figures of merit for two specific cases using Ashby's approach [1]. Figure S1 considers a pyroelectric element polarised through its thickness, that has electrodes located on its upper and lower surfaces. The pyroelectric has a thickness (*t*), electrode area (*A*) and is subject to a thermal excitation (ΔT).

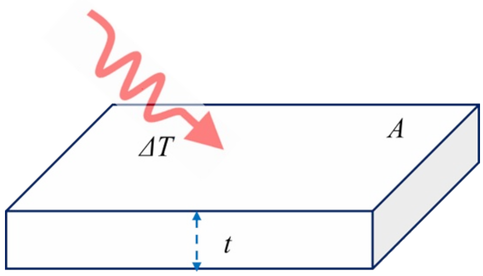

Fig. S1 The pyroelectric material with thickness and electrode area

CASE 1: Maximise the power (P_{max}) from a specific temperature change (ΔT) for a pyroelectric of element of specified geometry (*A*, *t*) by maximising the operating frequency (f_{max}).

We attempt to maximize the output power (P_{max}) for a pyroelectric element of specific thickness (*t*), and area (*A*) that is subject to a specific temperature change, ΔT; the thermal frequency (*f*) is a *free variable*,

P_{max} can therefore be written as the *objective function*:

$$P_{max} = Ef_{max} \tag{1}$$

According to Eqn. 10 (in the main paper body), the constraint to maintain homogenous heating is given by;

$$f_{max} = \frac{K}{\pi t^2} \tag{2}$$

Based on Eqn. 15 (in the main paper body), the energy for a single thermal cycle is:

$$E = \frac{1}{2}\frac{p^2}{\varepsilon_{33}^{\sigma}}(\Delta T)^2 At \tag{3}$$

By substituting Eqns. (2) and (3) into (1), we can eliminate the free variable (f_{max}) and P_{max} can be written as:

$$P_{max} = \frac{1}{2}\frac{p^2}{\varepsilon_{33}^{\sigma}}(\Delta T)^2 At \frac{K}{\pi t^2} = \frac{p^2 K}{\varepsilon_{33}^{\sigma}}(\Delta T)^2 (\frac{A}{2\pi t}) \quad (4)$$

$P_{max} = f$(materials properties). f(thermal load). f(geometry)

Since ΔT, A and t in Eqn. 4 are constrained to specific values, to maximise the power there is a need to maximise $\frac{p^2 K}{\varepsilon_{33}^{\sigma}}$.

This leads to the first *pyroelectric power figure of merit* F_{P1}, as defined in Eqn. 21 of the main paper, which is given by:

$$F_{P1} = \frac{p^2 K}{\varepsilon_{33}^{\sigma}} \quad (5)$$

CASE 2: We now consider a case where there is a need to maximise the power (P_{max}) from a specific temperature change (ΔT) that is fluctuating at a specific frequency (f) for a pyroelectric of element of specific area (A). In this case the thickness (t) of the element can be varied (i.e. it is a free variable).

P_{max} can therefore be written as the *objective function*:

$$P_{max} = E_{max} f \quad (6)$$

To maximize the output power (P_{max}) with variable t, there are constraints on A and ΔT and f. According to Eqn. (2), the maximum thickness that can maintain homogeneous heating is given by:

$$t_{max} = \left(\frac{K}{\pi f}\right)^{1/2} \quad (7)$$

Based on Eqn. 15 (in the main paper body), the energy for a single cycle is

$$E = \frac{1}{2}\frac{p^2}{\varepsilon_{33}^{\sigma}}(\Delta T)^2 At \quad (8)$$

Substitute Eqn. (7) and (8) into (6) to eliminate the free variable (t_{max}), the power P_{max} can be written as:

$$P_{max} = \frac{\frac{1}{2}\frac{p^2}{\varepsilon_{33}^{\sigma}}(\Delta T)^2 Atf}{} = \frac{p^2 K^{1/2}}{\varepsilon_{33}^{\sigma}}(f)^{1/2}(\Delta T)^2 \frac{A}{2\pi^{1/2}} \quad (9)$$

$P_{max} = f$ (materials properties). f (thermal load). f (geometry)

Since the constraints ΔT, f, and A are fixed in Eqn. 7, to maximise the power, there is a need to maximise $\frac{p^2 K^{0.5}}{\varepsilon_{33}^{\sigma}}$.

This leads to the *third pyroelectric power figure of merit F_{P3}*:

$$F_{P3} = \frac{p^2 K^{0.5}}{\varepsilon_{33}^{\sigma}} \quad (10)$$

References:

[1] Michael F. Ashby. Materials Selection in Mechanical Design, Pergamon Press, Oxford, U.K, 1992.