$p \times n$-Type Transverse Thermoelectrics: Driving Perpendicular Heat Flow in Type II Superlattices of InAs/GaSb

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We introduce a band-engineered transverse thermoelectric with *p*-type Seebeck in one direction and *n*-type orthogonal, resulting in off-diagonal terms that drive heat flow transverse to electrical current [1]. We name such materials $p \times n$ ("p-cross-n") type transverse thermoelectrics. Whereas thermoelectric performance is normally limited by the figure of merit ZT, transverse thermoelectrics can achieve arbitrarily large temperature differences in a single leg Peltier cooler even with inferior *ZT* by being geometrically tapered. Similarly, a single meander line geometry can result in large Seebeck voltage generation, exceeding the optimal performance of a rectangular leg of standard thermoelectric. An intuitive microscopic model is introduced to explain the transverse thermoelectric effect in $p \times n$ materials, which are shown to have advantages for microscale devices and cryogenic temperatures—exactly the regimes where standard longitudinal thermoelectrics fail.

Figure 1 below introduces a microscopic model of a $p \times n$-type semiconductor, with electrons dominating current along the *b*-axis, and holes dominating current along the *a*-axis. The crossed-arrow symbol in the upper right labels the *n* and *p* axes. Transverse thermoelectric behavior is achieved when electrical currents J_x and heat currents Q_y flow at close to 45 degrees relative to the *n*- and *p*- axes, as shown. An expression for the optimal transverse figure of merit $Z_\perp T$ and the optimal current/heat flow angle θ is derived.

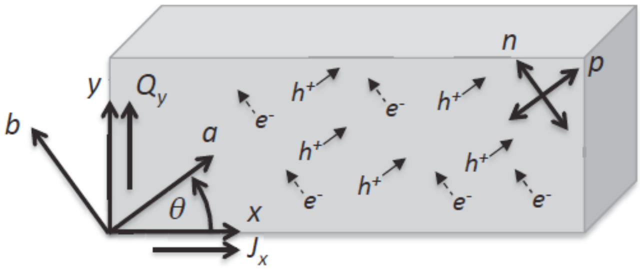

Figure 1. $p \times n$–type transverse thermoelectrics. Materials with *n*-type Seebeck perpendicular to a *p*-type Seebeck (notated with crossed arrows, upper right) can function as transverse thermoelectrics, driving thermoelectric heat flow perpendicular to an applied current.

A band-structure engineering strategy is described, whereby alternating InAs and GaSb layers in a wide-period superlattice can give rise to the desired $p \times n$ Seebeck tensor. A literature survey shows some anisotropic bulk semiconductors also have the necessary $p \times n$–type Seebeck behavior, such as $CsBi_4Te_6$ and $ReSi_{1.75}$.

[1] Chuanle Zhou, S. Birner, Yang Tang, K. Heinselman, and M. Grayson, (accepted to Phys. Rev. Lett. 2013)