Effects of disorder in topological band insulators and their thermoelectric figure of merit

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Recent extensive researches in condensed matter physics have established the existence of `topological band insulator' in semiconductors with strong relativistic spin-orbit interaction [1]. Topological band insulator is an unconventional band insulator, which has a topological surface metallic state, while being electrically insulating in the bulk. The existence of the surface metallic state profoundly originates from a certain topological character of Bloch wavefunctions in the insulating bulk, and its stability is protected only by the time-reversal symmetry [1]. It turns out that most of these topological band insulators are realized in well-acquainted materials, which have large thermoelectric figures of merit at the ambient temperature [2]. For example, thermoelectric devices widely-commercialized in the industry use as their thermoelectric conversion elements Bismuth Telluride, which is now recognized as the most idealistic topological band insulator. This observation leads to a following question; ``Why a number of topological band insulators happen to have high thermoelectric figures of merit at the ambient temperature?''

The thermoelectric figure of merit ZT is a dimensionless quantity, which measures its ability of transforming heat into electricity. It consists of three distinct transport coefficients; thermoelectric power S, electric conductivity σ, and thermal conductivity κ as $ZT = S^2\sigma T/\kappa$. When one either makes a crystalline material into a powder-sample or intentionally introduces lattice defects into a system, phonon propagations are strongly disturbed by these disorders, leading to an effective suppression of its thermal conductivity κ. However, such perturbations also affect an electronic system, so that, in a usual metal or semiconductor, not only the thermal conductivity κ but also its electric conductivity σ and thermoelectric power S are substantially suppressed. Having the latter two transport coefficients as its numerator, the thermoelectric figure of merit is not necessarily enhanced by these disorderings.

When these `time-reversal symmetric' disorderings are introduced in the topological band insulator, however, the situation changes drastically. On increasing the strength of the disorder, an electrically insulating bulk always becomes metallic at a certain intermediate strength of the disorder. More importantly, the existence of such disorder-induced bulk-metallic phase is necessitated by the stability of the topological surface metallic state; the disorder-induced metallization is a universal bulk-property of the topological band insulator [3]. This suggests that, contrary to a usual metal or semiconductor, the figure of merit in the topological band insulator have a maximum (at least a local maximum) near the disorder-induced metallic phase.

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