# Scaling Law for Energies of Bound States in Normal and Topological Crystalline Insulator Quantum Wells

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Some of IV-VI compounds with a rock-salt type lattice (SnTe as well as certain solid solutions like (Pb,Sn)Te, and (Pb,Sn)Se) are examples of topological crystalline insulators (TCIs). In bulk crystals of these materials inverted band ordering, tunable with Sn content, leads to the emergence of in-gap states with massless Dirac-like energy dispersion and helical spin structure. These so-called topological states are bound to the surfaces as well as to the interfaces between the TCI and a normal insulator (NI).

In thin TCI layers the spectrum can become gapped, due to the hybridization between topological states from nearby interfaces. Surprisingly, the electronic structure of such two-dimensional (2D) systems can be also topologically non-trivial, and, depending on the growth direction and layer thickness, can be described as a $Z_2$ topological insulator [1,2] or a 2D TCI [3]. The edges of these structures would feature one-dimensional spin-polarized channels of quantized conductance, sought as building blocks of novel spintronic devices and dissipationless transistors. The edge current predicted theoretically for free-standing films of SnTe and SnSe [1-3], remains still unobserved. A solution to this problem can come from thin TCI layers in planar heterostructures, e.g. (Pb,Eu)Se/(Pb,Sn)Se quantum wells (QWs), which are easier to realize experimentally than free-standing layers..

In this communication we employ the effective mass approximation to explore the electronic structure of TCI-based heterostructures forming either typical symmetric QWs or asymmetric QWs with barrier on one side and vacuum on the other. Our study has been specifically performed for (Pb,Eu)Se/(Pb,Sn)Se structures, with varying fraction of Sn in the QW material and various QW widths. It reveals that the QW energy levels follow simple scaling laws, depending on the sign of the bulk gap of the QW material. In QWs made of TCI materials we recover also the result that the energies of in-gap sub-bands, predicted by Korenman and Drew already in 1987 [4], are determined by the hybridization between the topological states on the two QW surfaces (interfaces). Additionally we find, that the hybridization strength is different for symmetric and asymmetric QWs, and, as proven by empirical tight-binding modeling, it can be further altered by changing the type of QW surface termination. The results are comparable to angle-resolved photoemission spectroscopy maps performed on (Pb,Eu)Se/(Pb,Sn)Se QWs grown by molecular beam epitaxy [5].

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[1] S. Safaei, M. Galicka, P. Kacman, and R. Buczko, *New J. Phys.* **17**(6), 063041 (2015)
[2] J. Liu and L. Fu, *Phys. Rev. B* **91**(8), 081407 (2015)
[3] J. Liu et al., *Nat. Mater.* **13**(2), 178–183 (2014)
[4] V. Korenman and H. D. Drew, *Phys. Rev. B* **35**(12), 6446–6449 (1987)
[5] G. Springholz, private communication