Band Structure Engineering and Ferroelectric Rashba Effect in IV-VI Topological Crystalline Insulator Heterostructures

Gunther Springholz*

Institut of Semiconductor and Solid State Physics, Johannes Kepler University, A-4040 Linz, Austria

gunther.springholz@jku.at

Topological matter has emerged as a powerful platform to generate relativistic Dirac, Weyl and Majorana quasiparticles based on the fundamentally different behavior of materials belonging to different topology classes. Of particular interest are systems in which the topology can be tuned and manipulated to pin down how topological phase transitions affect the physical behavior of the system. Topological crystalline insulators (TCI) of lead-tin chalcogenide IV-VI semiconductors (Pb-Sn-Ge tellurides and selenides) are particularly interesting in this respect because the topology of their electronic band structure is dictated by crystalline symmetries and thus, are particularly sensitive against internal or external perturbations. In this work, band structure and strain engineering of epitaxial TCI heterostructures produced by molecular beam epitaxy is presented and examples of various means of how the band topology of these systems can be controlled and manipulated are demonstrated.

Particular focus will be on direct imaging of the electronic structure and topological surface states by angle resolved photoemission spectroscopy performed at synchrotrons on MBE grown structures that allows to unravel many effects in great detail in momentum space (Fig. 1). By this, we demonstrate how topological interface states depend on the hybridization in quantum confined structures and how these states can be tuned by strain, surface and bulk doping as well as by ferroelectric phase transitions that lift the valley degeneracy and induce a large Rashba effect [1-4]. Examples include the formation of Volkov-Pankratov states in compositionally grades TCI heterostructures, counter propagating edge states and the resulting unique bipolar quantum Hall effect in strained QWs, as well as the emergence of a giant Rashba splitting in ferroelectric systems produced by germanium doping.

***Collaborators:** G. Krizman, T. Zakusylo, M. Hajlaoui, T. Takashiro, G. Bauer (JKU-Linz), J. Bermejo-Ortiz, Y. Guldner, L.-A. de Vaulchier (ENS-Paris), Ondrej Caha, L. Sajeev (Masaryk University Brno), R. Rechciński, M. Galicka, R. Buczko, P. Kacman, V.V. Volobuev (IFPAN-Warzawa), J. Sánchez-Barriga, O. Rader, A. Varykhalov (BESSY-Berlin), F. Chassot, G. Kremer, C. Monney (Univ. Fribourg), J. H. Dil, J. Krempaský (PSI Villigen), Ján Minár, A. Pulkkinen (University Pilsen), B.A. Assaf (Notre Dame).

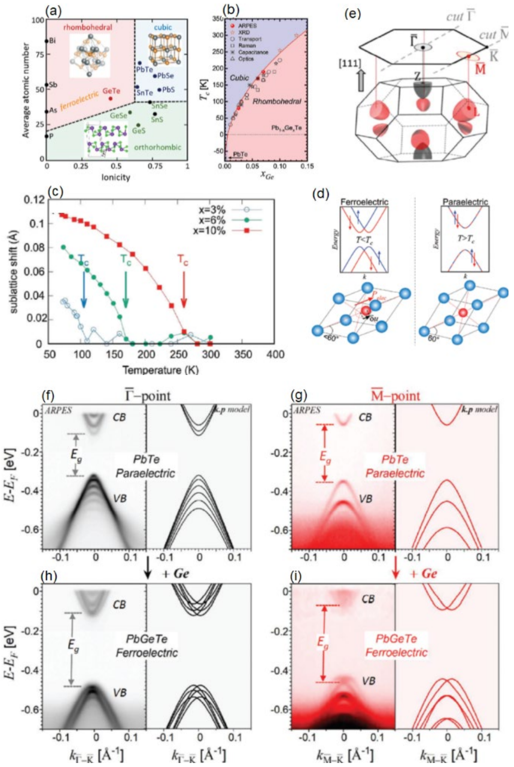

Fig. 1: Ferroelectric Rashba effect in IV-VI materials. (a-c) Phase diagrams of IV-VI compounds and ferroelectric phase transition in PbGeTe. The resulting ferroelectric Rashba effect is shown in (d). (e) Brillouin zone of the IV-VI compounds with the band extrema at the L-points. (f-i) ARPES maps of paraelectric and ferroelectric $Pb_{1-x}Ge_xTe$ QWs recorded at the Γ (grey) and M-points (red). See Ref. [4].

References

[1] R. Rechciński et al., Adv. Funct. Mater. **31**, 2008885 2021).
[2] G. Krizman et al., Phys. Rev. Lett. **132**, 166601 (2024).
[3] J. Bermejo-Ortiz, et al., Phys. Rev. B **107**, 075129 (2023).
[4] G. Krizman et al., Advanced Materials 36, 2310278 (2024)