Emergent quantum spin Hall phase in GeSn heterostructures on silicon

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Topological phases of solid-state electron systems look poised to provide solutions that will revolutionize information technologies [1]. One of the challenges to translate topologically enriched devices from research lab to scale-up production remains the recurrent use of environmentally-polluting or resource-critical materials. To overcome this limitation, we propose a practical silicon-based architecture that spontaneously sustains topological properties, while being fully compatible with the high-volume manufacturing capabilities of modern microelectronic foundries [2]. Here we show how conventional semiconductors such as $Ge_{1-x}Sn_x$ alloys can be engineered into heterojunctions that demonstrate a broken gap alignment. We predict such basic building block undergo a quantum phase transition that can elegantly accommodate the existence of gate-controlled chiral edge states directly on Si (see the schematics in Fig. 1). This will enable the design of integrated circuits hosting quantum spin hall insulators, thus bringing topological functionalities a step closer to their use in future consumer electronics.

References

[1] J. E. Moore, Nature 464, 194 (2010).

[2] B. M. Ferrari, F. Marcantonio, F. Murphy-Armando, M. Virgilio, and F. Pezzoli Phys. Rev. Research 5, L022035 (2023).

Figures

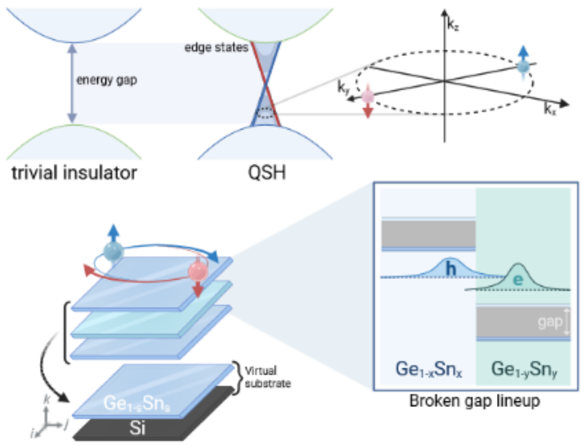

Figure 1: Quantum spin Hall (QSH) phase emergent in $Ge_{1-x}Sn_x/Ge_{1-y}Sn_y$ architectures. A strained $Ge_{1-x}Sn_x/Ge_{1-y}Sn_y$ heterostructure integrated on silicon through a $Ge_{1-s}Sn_s$ virtual substrate can host topologically protected edge states featuring spin-momentum locking. A quantum phase transition from a trivial to a quantum spin hall insulator can spontaneously occur in the system when the heterojunctions demonstrate a broken-gap alignment of the band offsets. This can lead to an inverted band structure with hole states higher in energy than the electron states, while giving rise to an interface electric dipole because of the accumulation of opposite charges at opposite sides of the junction.