

Quantum spin Hall effect and topological insulators

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Recently, a new class of topological states has been theoretically predicted and experimentally realized. The topological insulators have an insulating gap in the bulk, but have topologically protected edge or surface states due to the time reversal symmetry. In two dimensions the edge states give rise to the quantum spin Hall (QSH) effect, in the absence of any external magnetic field. I shall review the theoretical prediction [1] of the QSH state in HgTe/CdTe semiconductor quantum wells, and its recent experimental observation [2]. The edge states of the QSH state support fractionally charged excitations [3]. The QSH effect can be generalized to three dimensions as the topological magneto-electric effect (TME) of the topological insulators [4]. Topological insulators Bi₂Te₃, Bi₂Se₃ have been discovered theoretically and experimentally to have surface states consisting of a single Dirac cone [5,6,7]. I shall present a realistic experimental proposal to observe the magnetic monopoles on the surface of topological insulators [8]. Various spintronics applications based on topological insulators will be discussed. [1] A. Bernevig, T. Hughes and S. C. Zhang, *Science*, 314, 1757, (2006) [2] M. Koenig et al, *Science* 318, 766, (2007) [3] J. Maciejko, Chaoxing Liu, Yuval Oreg, Xiao-Liang Qi, Congjun Wu, and Shou-Cheng Zhang, *Phys. Rev. Lett.* 102, 256803 (2009). [4] Xiao-Liang Qi, Taylor Hughes and Shou-Cheng Zhang, *Phys. Rev B* 78, 195424 (2008) [5] Haijun Zhang, Chao-Xing Liu, Xiao-Liang Qi, Xi Dai, Zhong Fang, and Shou-Cheng Zhang, *Nature Physics* 5, 438 (2009). [6] Y. Xia, L. Wray, D. Qian, D. Hsieh, A. Pal, H. Lin, A. Bansil, D. Grauer, Y. Hor, R. Cava, et al., *Nat. Phys.* 5, 398 (2009). [7] Y. L. Chen, J. G. Analytis, J.-H. Chu, Z. K. Liu, S.-K. Mo, X.L. Qi, H. J. Zhang, D. H. Lu, X. Dai, Z. Fang, et al., *Science* 325, 178 (2009). [8] Xiao-Liang Qi, Run-Dong Li, Jiadong Zhang and Shou-Cheng Zhang, *Science* 323, 1184 (2009).

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