Topological Insulator in the Presence of Spatially Correlated Disorder

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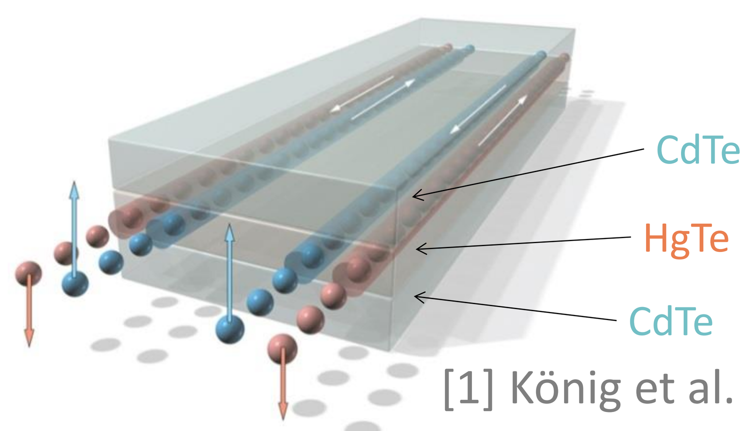
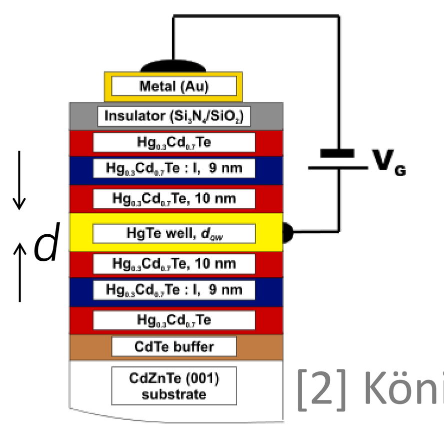
Two-dimensional topological Insulators



[1] König et al.



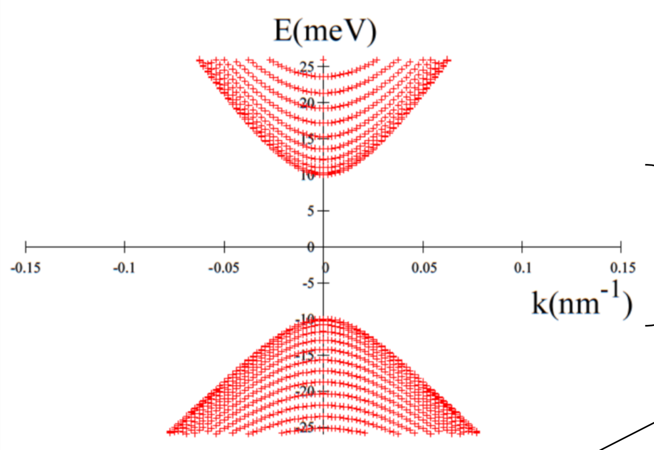
[2] König et al.

thickness d of quantum well increased

ordinary insulator $m > 0$ → topological insulator $m < 0$

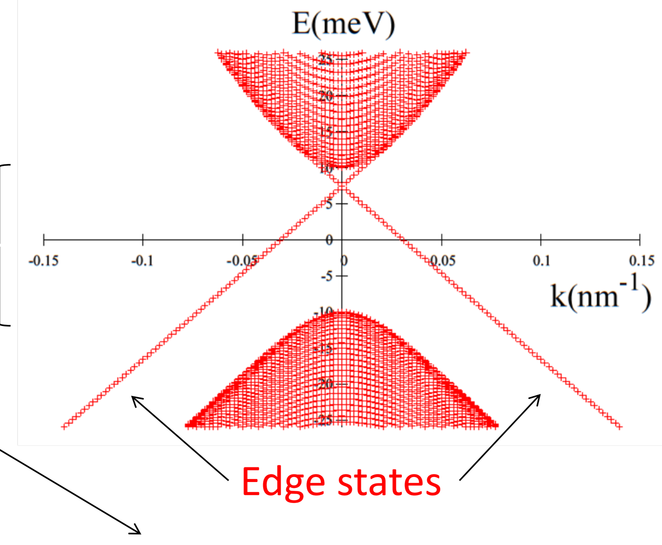
phase transition

parametrized by topological mass m



bulk band gap

$-|m| < E_F < +|m|$



insulating behavior

pure edge transport – quantum spin Hall phase – experimentally verfied in [1]

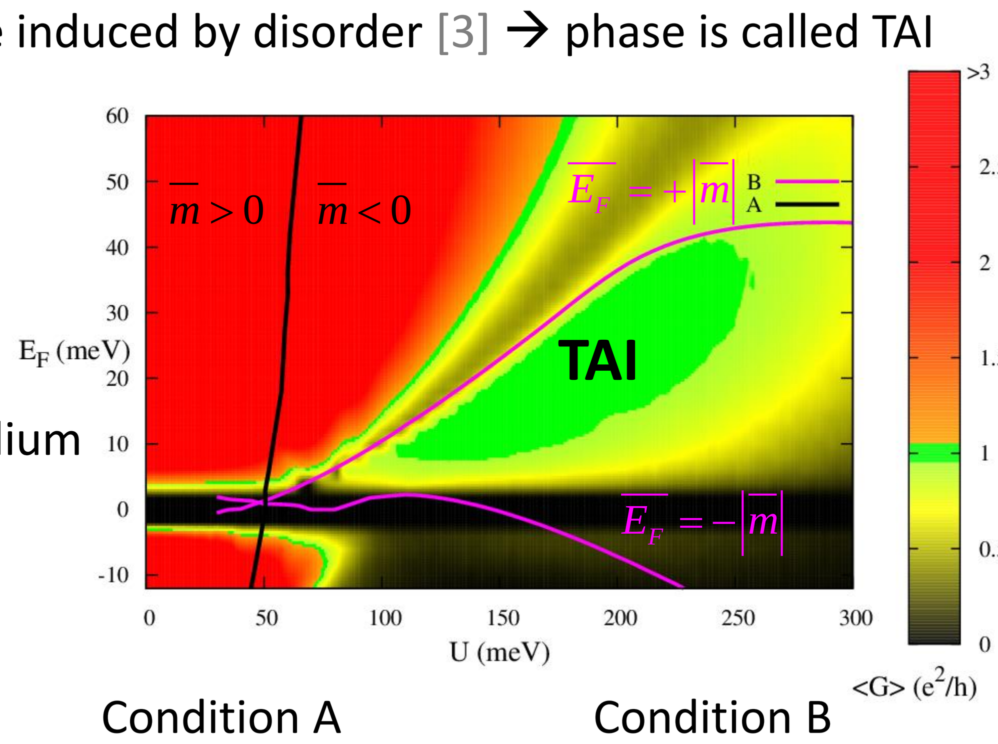
Topological Anderson Insulator (TAI)

similar phase transition can also be induced by disorder [3] → phase is called TAI

- ordinary insulator with $m=2$ meV
- for increasing disorder strength U: transition into TAI phase

understood in terms of effective medium theory [4] with new parameters:

$m \to \bar{m}$ and $E_F \to \bar{E}_F$



appearance of TAI determined by:

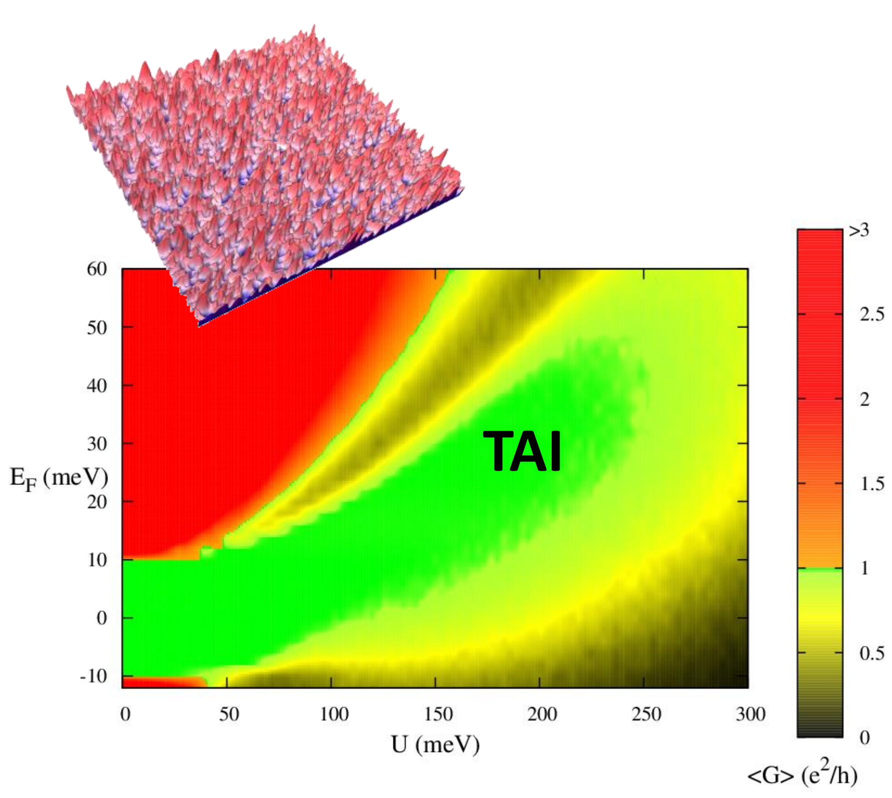
Condition A: $\bar{m} < 0$

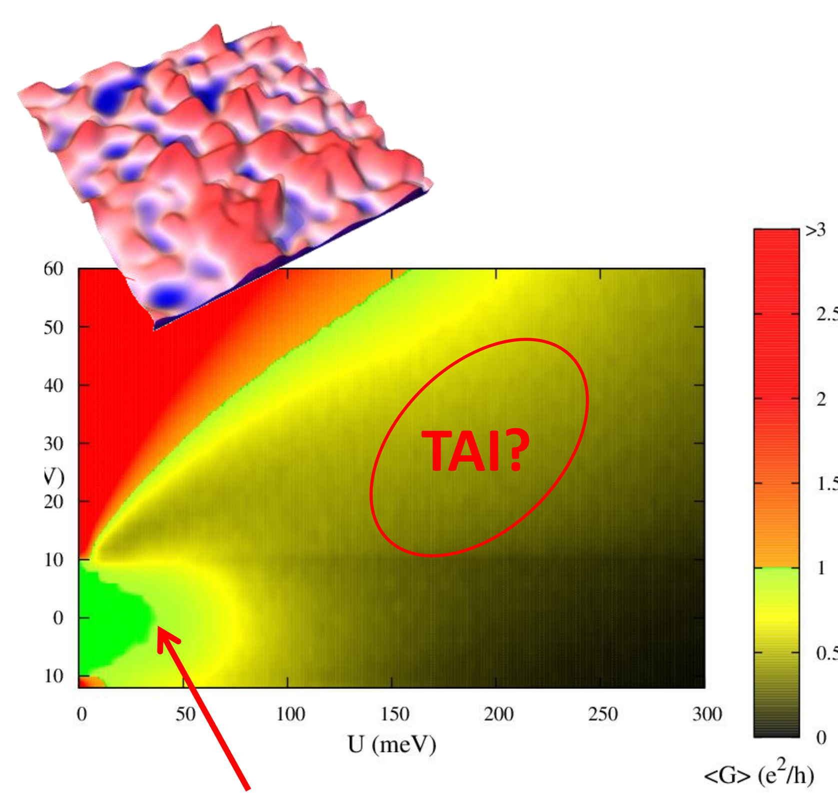
Condition B: $-|\bar{m}| < \bar{E}_F < +|\bar{m}|$

Spatial Correlations in the Disorder

- previous investigations: disorder with spatially uncorrelated random values
- more realistic approach: correlated disorder with correlation length ξ
- spatial disorder correlations always present in nature!
- effects of correlations on TAI and on robustness of edge states?

uncorrelated case → correlated case

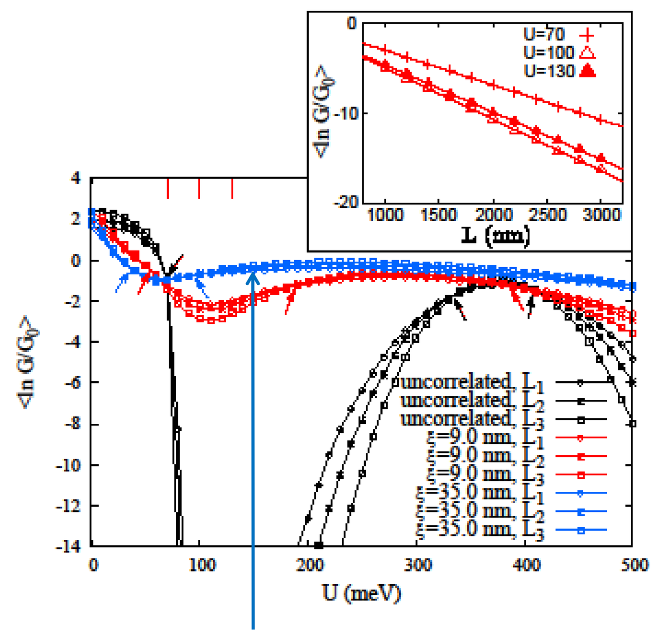


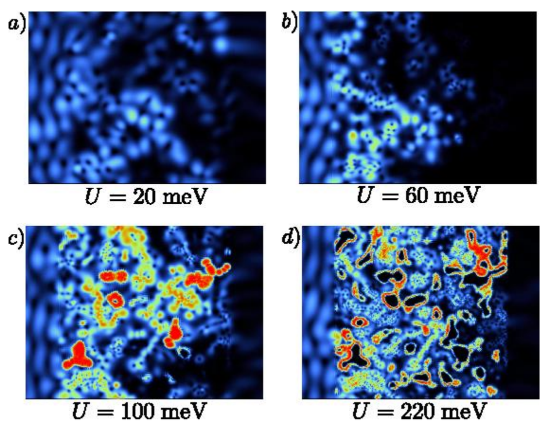


edge states not robust?

TAI disappears if correlations are present!

Scaling analysis





- rolling up system to a cylinder [5]
- crossing points (small arrows) show where bulk system becomes insulating / conducting
- correlated disorder: bulk gap is filled with localized bulk states (see inset)
- insulating region between 1st and 2nd crossing point (small arrows): TAI can still occur in infinitely large samples
- bulk states undergo localization-delocalization transition for strong disorder
- for correlated disorder: percolation transition as in Quantum Hall effect

Effective Medium Theory for Correlated Disorder

effective medium theory for uncorrelated case [4] *(a ... grid constant)*

self energy $\Sigma = \frac{U^2}{12}\left(\frac{a}{2\pi}\right)^2 \lim_{\kappa\to 0} \int_{-\pi/a}^{\pi/a}\int_{-\pi/a}^{\pi/a} dk_y dk_x \left(E_F + i\kappa - H_0(\vec{k},a) - \Sigma\right)$

decomposition into Pauli matrices $\Sigma = \Sigma_0\sigma_0 + \Sigma_x\sigma_x + \Sigma_y\sigma_y + \Sigma_z\sigma_z$

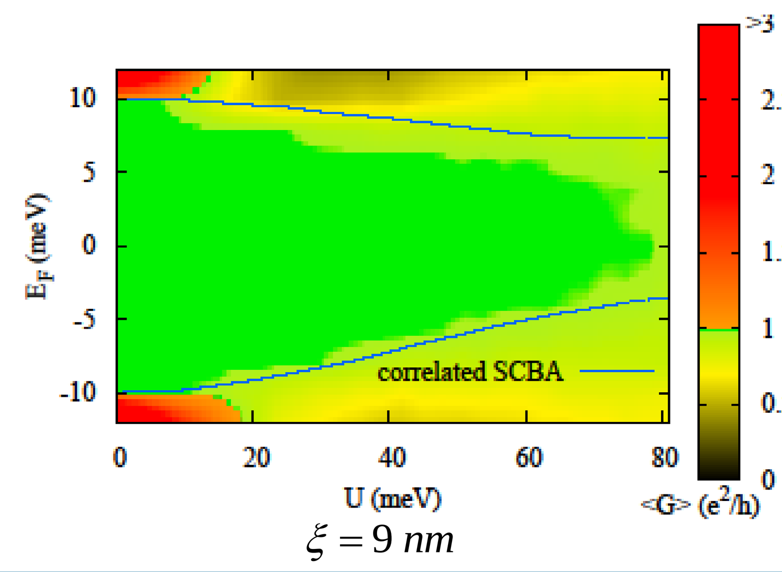
effective parameters given by $\bar{m} = m + \mathrm{Re}\,\Sigma_z$, $\bar{E}_F = E_F - \mathrm{Re}\,\Sigma_0$

in correlated case: correlation function of potential $\propto \exp(-\frac{r^2}{2\xi^2})$

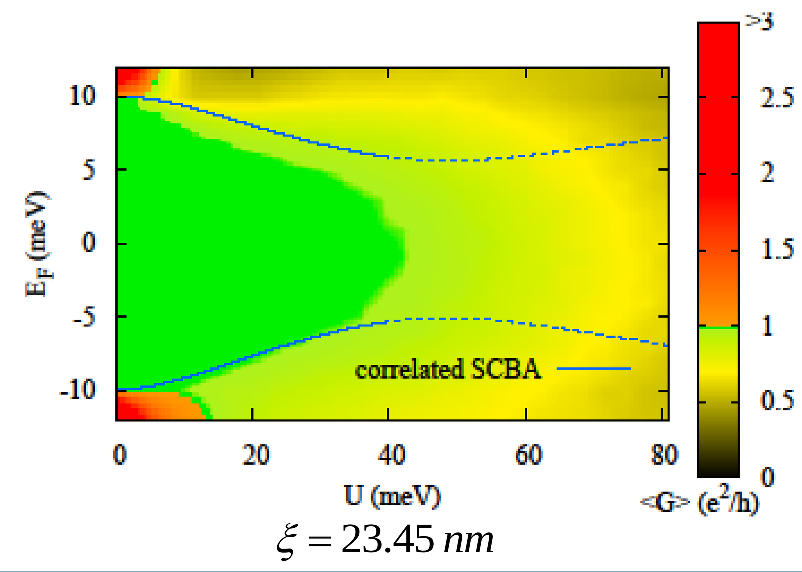
Fourier transform of correlation function $\tilde{C}(\vec{k})$ enters self energy equation

$$\Sigma = \frac{U^2}{12}\left(\frac{c\xi}{2\pi}\right)^2 \lim_{\kappa\to 0} \int_{-\pi/(c\xi)}^{\pi/(c\xi)}\int_{-\pi/(c\xi)}^{\pi/(c\xi)} dk_y dk_x \tilde{C}(\vec{k}) \left(E_F + i\kappa - H_0(\vec{k},a) - \Sigma\right)$$

generalized effective medium theory for new phase boundary!



$\xi = 9$ nm



$\xi = 23.45$ nm

Conclusions

- **correlations in the disorder destroy TAI phase**
- **edge states are not as robust as in uncorrelated case**
- **generalized effective medium theory works**
- **observation of percolation in correlated potentials**
- **Preprint available: arXiv:1212.0735**

References

[1] M. König, S. Wiedmann et al., Science 318, 766 (2007)
[2] M. König, H. Buhmann et al., J. Phys. Soc. Jpn. 77, 031007 (2008)
[3] J. Li, R. L. Chu et al., PRL 102, 136806 (2009)
[4] C. W. Groth, M. Wimmer et al., PRL 103, 196805 (2009)
[5] H. Jiang, L. Wang et al., Phys. Rev. B 80, 165316 (2009)

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