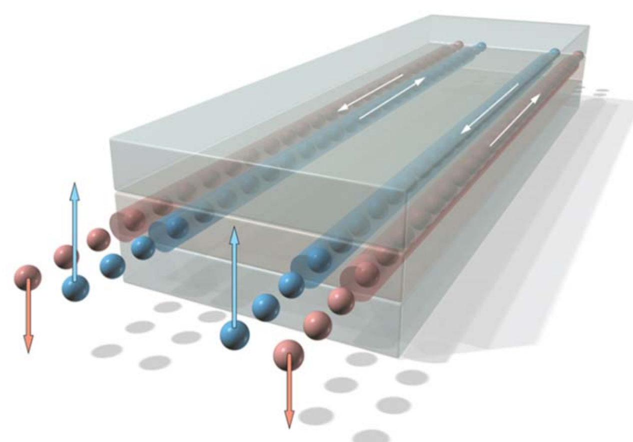
Superconductivity in $Cu_xBi_2Se_3$ and its Implications for Pairing in the Undoped Topological Insulator

Y. S. Hor, A. J. Williams, J. G. Checkelsky, P. Roushan, J. Seo, Q. Xu, H. W. Zandbergen, A. Yazdani, N. P. Ong, and R. J. Cava

Garrett Vanacore
Sean Vig
Jiang Wang
Xiaoxiao Wang



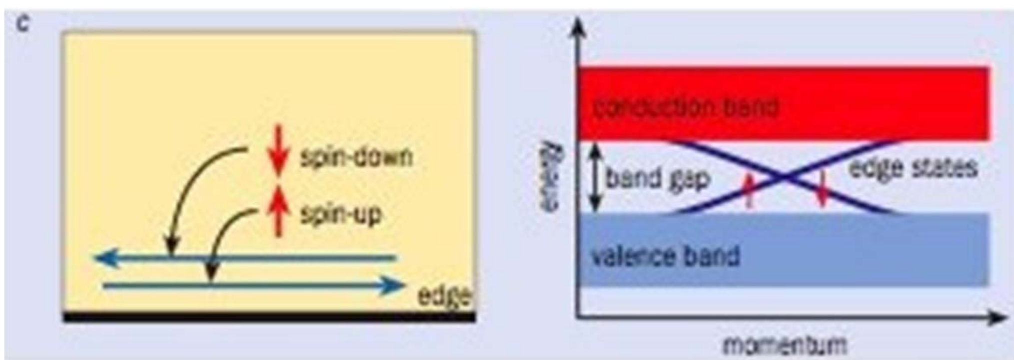
http://www.myscience.ch/news/2009/observation_of_unconventional_quantum_spin_texture

Outline of Talk

- Background and motivation
- Structure and synthesis of $Cu_xBi_2Se_3$
- Measurement and characterization of superconductivity in $Cu_xBi_2Se_3$
- Critiques and impact of paper

Topological Insulators

- Recently discovered state of matter that behaves like an insulator in its bulk (interior) and a conductor on its surface
- Surface states are “spin currents” -- spin-up and spin-down electrons propagating in opposite directions



C. Kane and J. Moore, *Physics World*, Feb. 2011

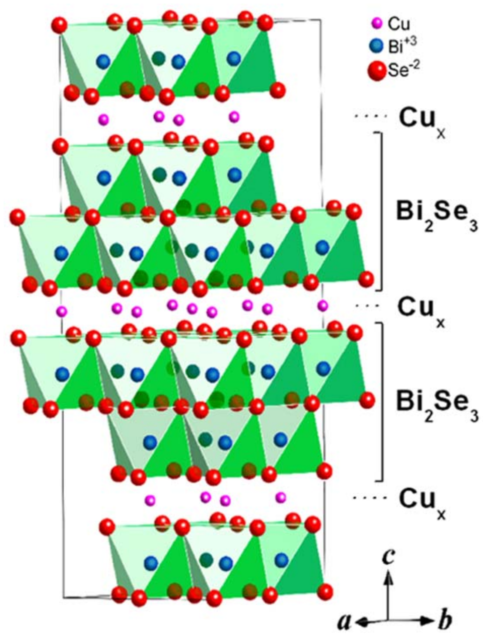
Surface States and Superconductivity

- It has been theorized that exotic quasiparticles could be generated and manipulated by depositing a superconductor on the surface of a topological insulator

- An experimental realization of these quasiparticles would be an important proof of concept for particle physicists, and could significantly advance experimental quantum computation

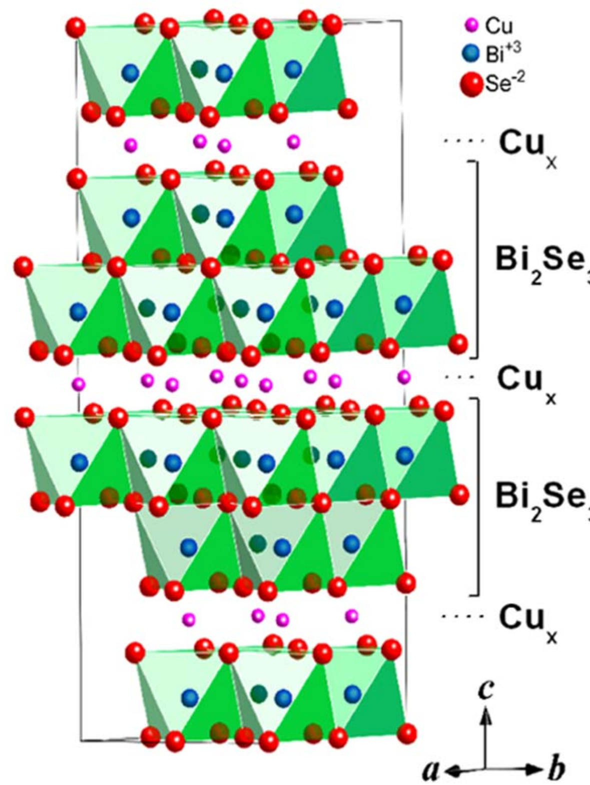
Research Motivation

- Hor *et al.* demonstrate that superconductivity can be induced in the topological insulator Bi_2Se_3 through intercalation of copper atoms



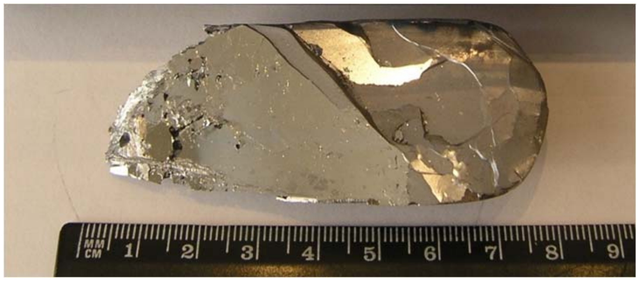
Crystal Structure

- Bi_2Se_3 is made from double layers of $BiSe_6$ octahedra
- Cu may either intercalate between the Se layers, $Cu_xBi_2Se_3$ or substitute for Bi, $Bi_{2x}Cu_xSe_3$
- They have substantial differences in the electrical properties



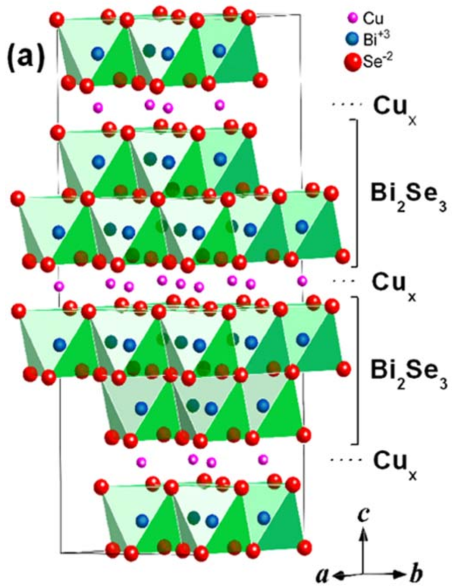
Crystal growth

- Melt stoichiometric mixtures of Bi (99.999%), Cu (99.99%), and Se (99.999%) at 850°C
- Slow cooling from 850 to 620 °C
- Quenching in cold water

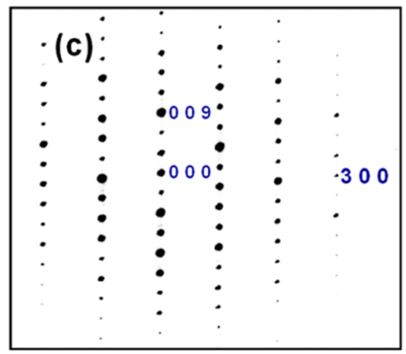


http://www.sttic.com.ru/lpcbc/DANDP/Bi-Ch.html

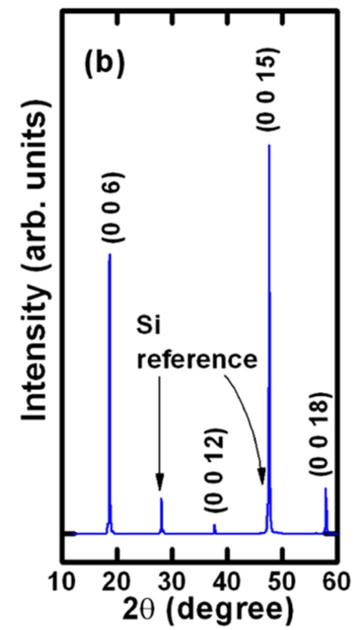
Structural analysis



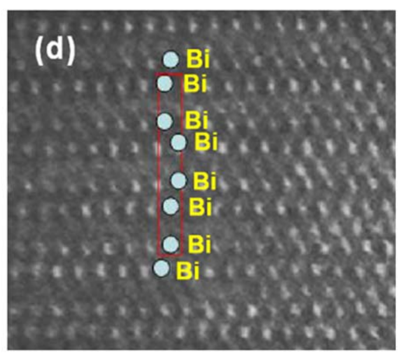
Electron diffraction pattern



X-ray diffraction scan



High resolution electron microscope image

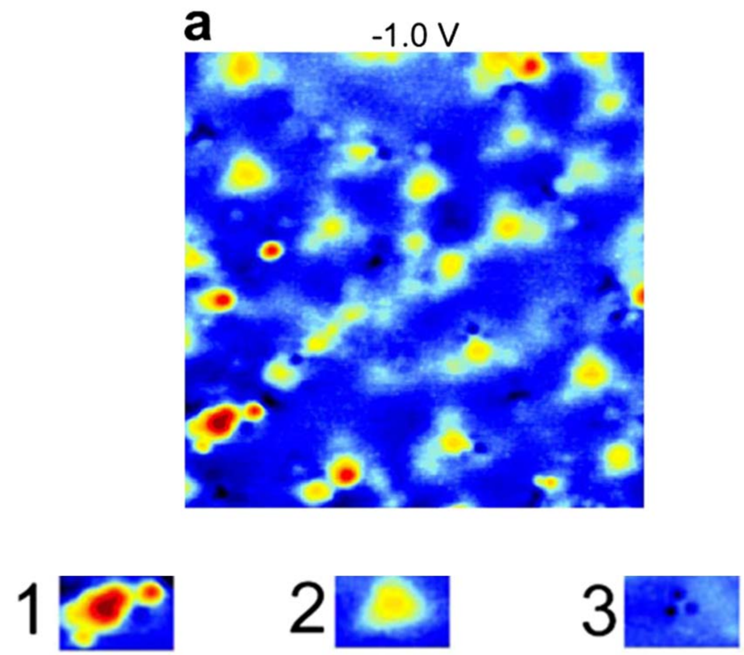


Structure Analysis Results 1

- Single crystal is chemically single phase
- Excellent crystalline quality on the long range
- Good crystal quality on the nanoscale
- However, no long or short range ordering of the Cu in the interstitial sites

Structure Analysis Results 2

(001) surface of a cleaved $Cu_{0.15}Bi_2Se_3$ single crystal using an STM at 4.2 K.



- type 1: located on the cleaved surface and are clusters of intercalated Cu atoms
- type 2: intercalated Cu in Van der Waals layers beneath the surface
- type 3: requires further study

Structure Analysis Results 2

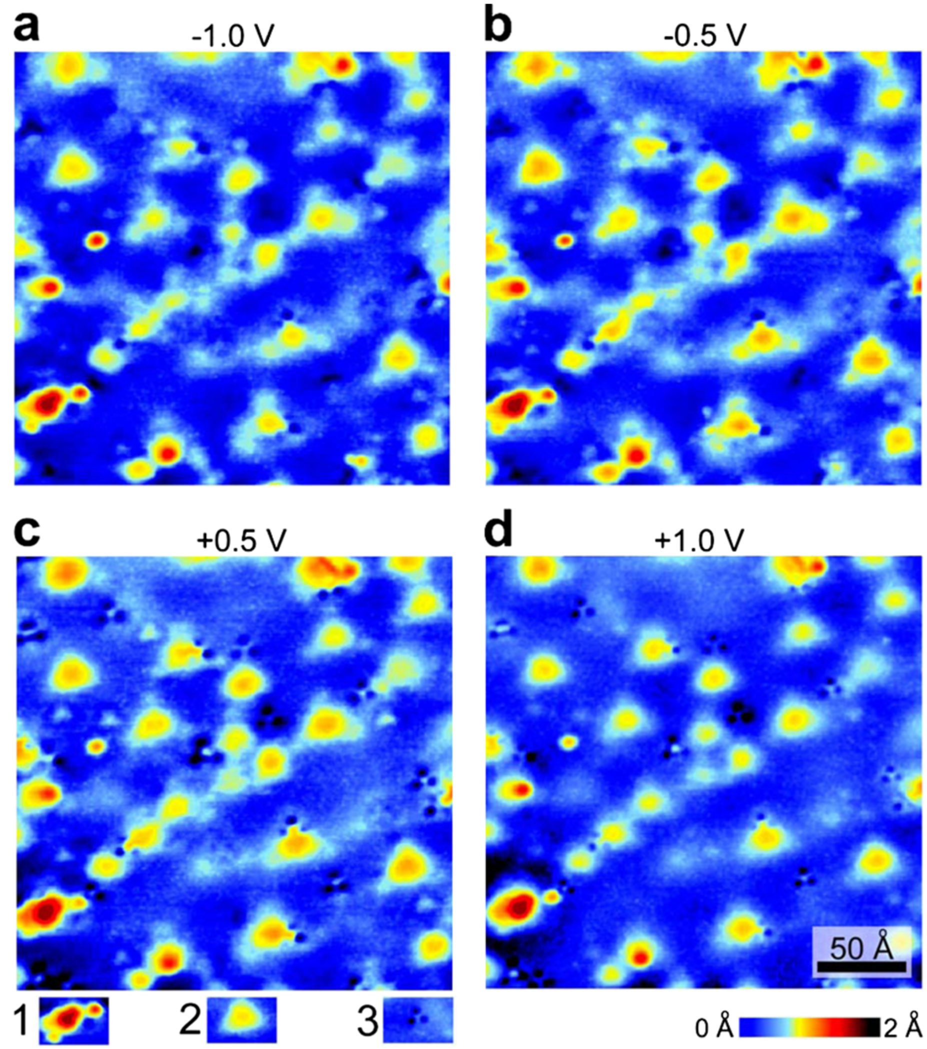
(001) surface of a cleaved $Cu_{0.15}Bi_2Se_3$ single crystal using an STM at bias voltages of

(a) -1.0 V

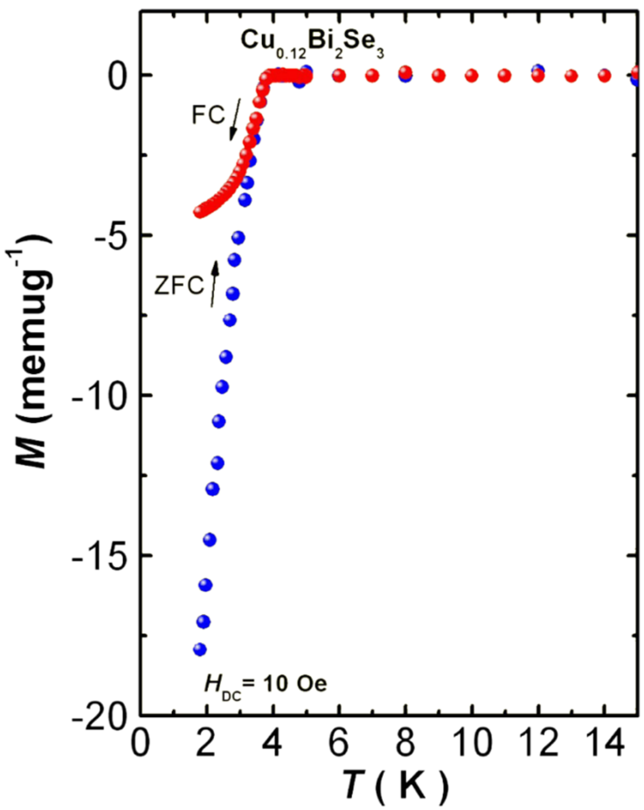
(b) -0.5 V

(c) +0.5V

(d) +1.0V.

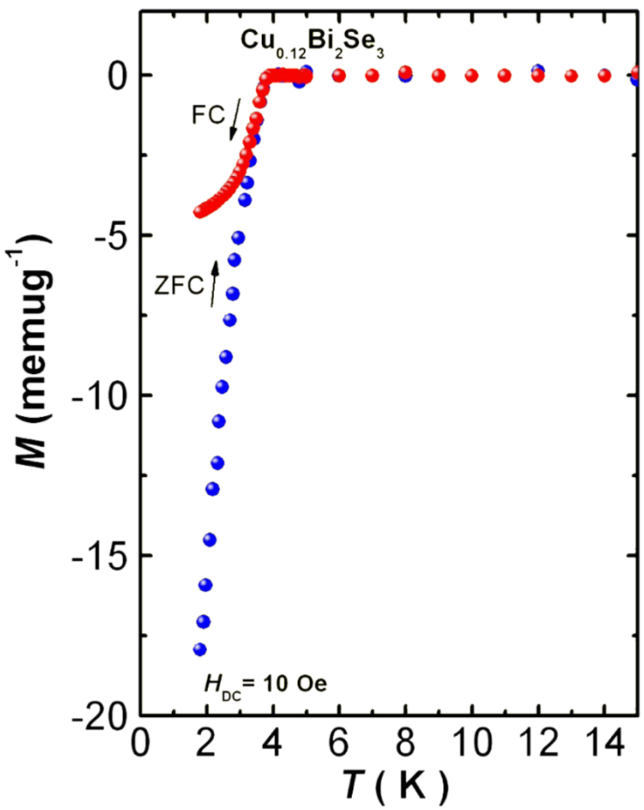


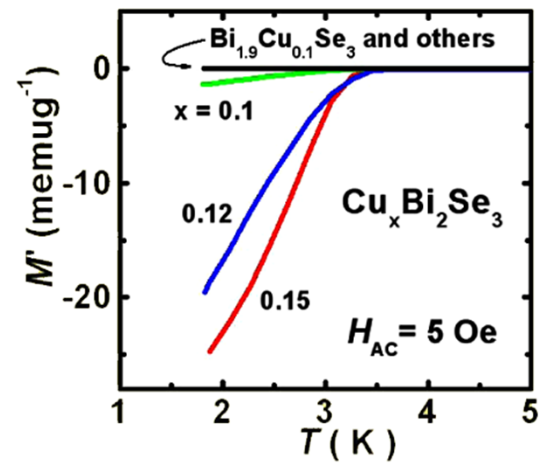
Zero-field- and field-cooled magnetization of $Cu_xBi_2Se_3$



- $Cu_{0.12}Bi_2Se_3$: T_c = 3.8 K
- 20% of expected magnetization

Zero-field- and field-cooled magnetization of $Cu_xBi_2Se_3$

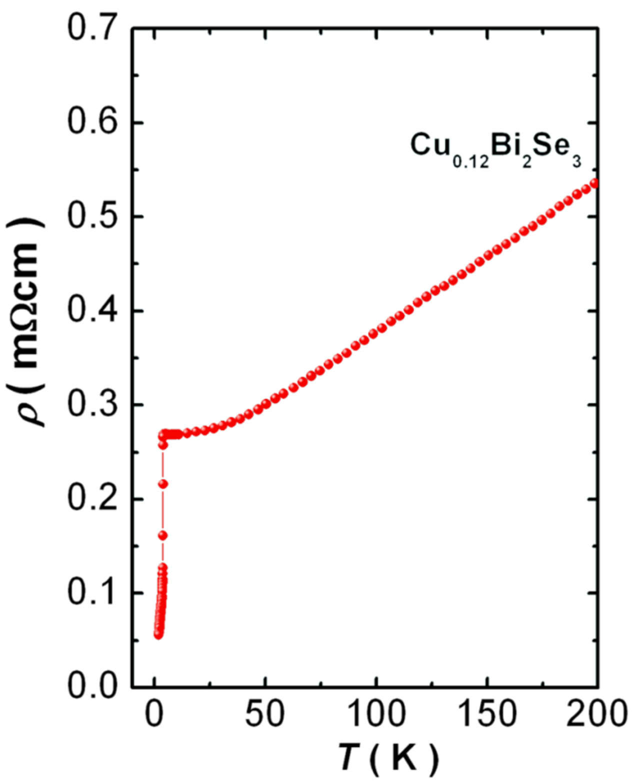


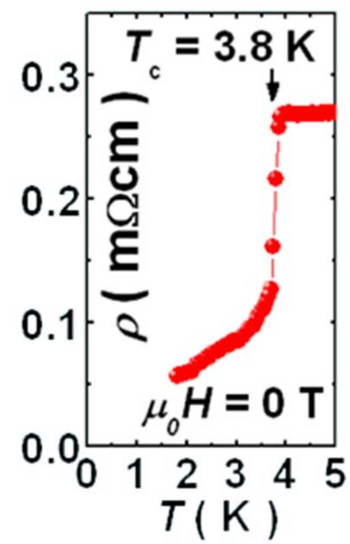


- $Cu_xBi_2Se_3$ superconducts for $0.1 \le x \le 0.3$
- Other samples do not superconduct

- $Cu_{0.12}Bi_2Se_3$: T_c = 3.8 K
- 20% of expected magnetization

Temperature dependent resistivity of $Cu_xBi_2Se_3$

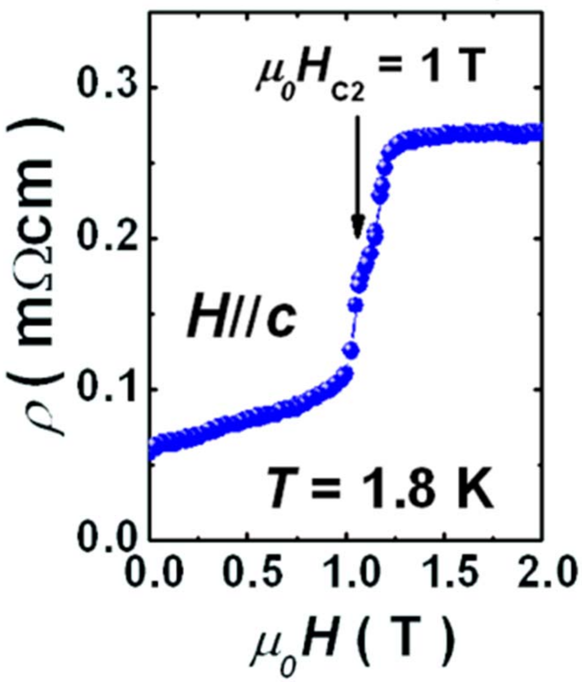




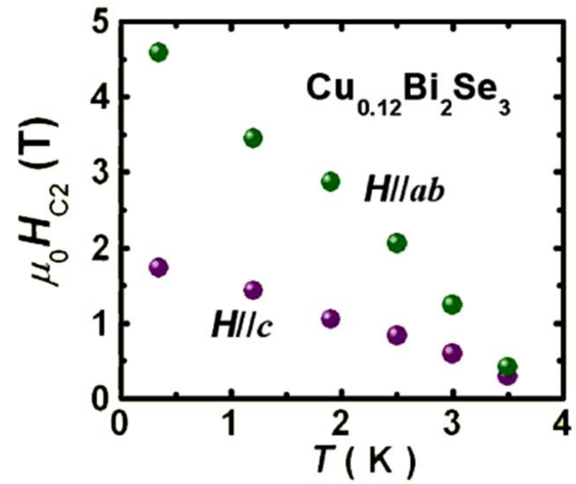
Blow up of figure on the left

- Carrier density ≈ 2×10^{20} cm^{-3}
- T_c = 3.8 K
- Non-vanishing resistivity

Temperature dependent resistivity of $Cu_xBi_2Se_3$



Magnetoresistance at 1.8 K for H ‖ c



Critical field as a function of temperature along basal plane and c axis

Temperature-dependent critical field at 0.3K:

- H ‖ c: H_{c2} = 1.7 T
- H ‖ ab: H_{c2} = 4.6 T

Conclusion

- **Cu** intercalation in Van der Waals gaps between $\mathbf{Bi_2Se_3}$
- Superconductivity of $\mathbf{Cu_{\mathit{x}}Bi_2Se_3}$ at 3.8K with x (0.12~0.15)

Critique

- **Credibility** The model is reasonable and the experimental process is standard, the data is credible
- **Innovation** The first time that Cooper pairing is reported in topological insulator, may have impact on future work

Unsolved Problems **&** Future Work

- $\mathbf{Bi_2Se_3} \rightarrow \mathbf{Bi_2Te_3}$?
- The specific heat of $\mathbf{Cu_xBi_2Se_3}$.(Has been done by Group 5's paper)
- Specific layer? Or The material itself?
- Replace **Cu** with other element and show similar result?

The Importance of Our Paper

- Our paper is an original work, it’s the first experimental reporting of superconductivity in a topological insulator
- Important for future quantum computation. (Majorana fermion)

Citing Information

- Very hot, 43 times/ past 1 year
- Still in basic researching stage

Journals (**43 Total**)
Physical Review B (17)
Physical Review Letters (7)
JETP Letters (2)
Journal of Applied Physics (2)
Nature Physics (2)
Reviews of Modern Physics (2)

Annual Review of Condensed Matter Physics (1)
MRS Proceedings (1)
Review of Scientific Instruments(1)
Physica E: Low-dimensional Systems and Nanostructures (1)

Thanks!