Characterization of Samarium Hexaboride (SmB₆), a Topological Insulator

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Quantum Physics and Band Theory

Energy

Empty bands

Filled bands

Insulator
\((\sigma = 0 \text{ at } T = 0 \text{ K})\)

Conductor
\((\sigma \neq 0 \text{ at } T = 0 \text{ K})\)

Completely filled bands cannot carry electrical current.
What is a Topological Insulator?

**Theoretical predictions**

- As $T \to 0$ K
  - Fully insulating bulk ($\sigma = 0$)
  - Conducting surface ($\sigma \neq 0$)
- Robust topologically protected surface
- Odd number of Dirac cones
- Strong correlation between electron spin and orbital momentum (Helical spin structure)
What is not a Topological Insulator?

Example:

- A topological insulator is not an “ordinary” or “trivial” insulator like diamond in which electrons fully occupy energy bands.
- Simply put, a topological insulator can not lose its insulating nor conducting parts via procedures such as polishing for example.
Surface States Observed in weakly correlated TI materials

Fancy example
Spin and angle resolved photoemission of Bi\textsubscript{2}Se\textsubscript{3}
Hasan group
Xia et al
Nat. Phys.
Science
2009

Spin polarized Dirac cone with helical spin texture at Fermi surface

But lacking simple transport studies because bulk typically has impurity conduction --- possible great opportunity for SmB\textsubscript{6}!!
Discovery of a True Topological Insulator

Device for Testing Surface vs. Bulk

Samarium Hexaboride (SmB₆)
SmB₆ is indeed fully insulating at the bulk and conducting on the surface at $T = 0\text{ K}$. 
Meaning and Importance of the Discovery

- Samarium Hexaboride (SmB$_6$) is the first true topological insulator
- We can now perform electrical measurements for a topological insulator
- We predict that different crystal directions might have different properties
- Surface properties are well seen when samples are well polished (IMPORTANT-Otherwise, I would not have anything to do this summer)
Preparing the samples

**Goal:**
Polish surfaces of different orientations for photolithography and Corbino fabrication

Samples before polishing

Corbino coated with gold

Aluminum

Void
Sample Size in Average
(100) Surface’s Polishing

- (100) surface

SmB$_6$ cubic crystal structure

Sample is a good candidate for 100 surface/plane.
We polished the "bottom side" to avoid the crack.

http://en.wikipedia.org/wiki
Polishing Station
(110) Surface’s Polishing

- Sample is a good candidate for any planes
- Given the length of the sample, if we broke it and polished Side A and Side B down to

  Side A

  Side B

then we would have two (110) surfaces.

* However, Side A did not survived.

* (110) surface
Samples after polishing

- Pictures were taken with a scanning electron microscope (SEM)
- Surface imperfections remained even after finer polishing
- Next step, we etched our samples
Etching Agents for SmB$_6$

**Goal:**
- Etch surfaces for cleaning purposes before photolithography.
- We would like to remove the oxide layers on the polished surfaces to avoid interference with the electrical measurements.

**Recipes:**
- Sample is placed in a solution of ~50% of hydrochloric acid and 50% of water for a hour.
- We submerge sample in a solution of ~50% of nitric acid and ~50% of water for 10 minutes.
Results/Conclusions

• The size of the SmB$_6$ crystals limits the variety of planes that can be obtained via polishing. While getting (100) and (110) surfaces seems to happen easily, we struggle with preparing (111) surfaces.

• Nitric acid etches the surface of a SmB$_6$ sample under normal conditions while hydrochloric acid (HCl) does not i.e. for cleaning purposes, HCl can be used.
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