Graphene as a Superconducting Weak Link

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Introduction

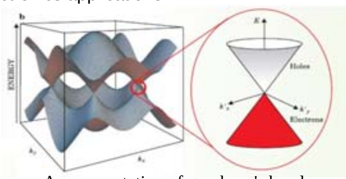
Graphene is an increasingly popular topic in modern solid state research. It's high electronic stability and quality at room temperature make it particularly distinctive, especially among two-dimensional constructions.

Cooper pair propagation through graphene is not immediately apparent from the initially found qualities. It has not been shown to be superconducting yet, but a couple of papers relating to using it as a superconducting weak link have been published[1][2]. However, a broader experimental investigatoin on the topic is still pending.

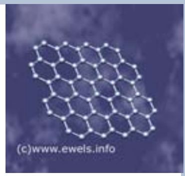
The goal of this work is to create a superconductor-graphene-superconductor (SGS) junction and observe some result from the superconducting proximity effect in the graphene.

Graphene

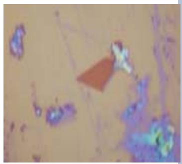
- An interconnected sp_2 network of carbon atoms
- High electron mobility and density
- Room temperature Quantum Hall Effect
- Unusual band structure first identified in 1947[3]
  - "Zero-gap semiconductor"
  - Electron behavior as a massless Dirac fermion near the Dirac point
- Potential future as various components or entire circuits in electronics applications.



A representation of graphene's band structure[4]



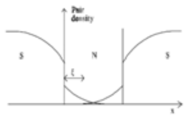
Atomic-level view of graphene structure



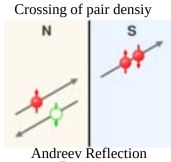
My first good sample

Superconducting Proximity Effect
The Josephson Junction

- Cooper Pair propogation
  - Cooper pairs can travel a *finite penetration depth* through other materials connected to superconductors
  - Graphene's is estimaed at ~1µm[2]
- Andreev Reflections
  - A normal conductance electron with the NS boundary to cooper pair.
- But graphene is not a normal metal
  - The results could be different or unusual
- Currently published work:
  - Multiple Andreev Reflections in Graphene[1]
  - Supercurrent in short and wide junctions[2]



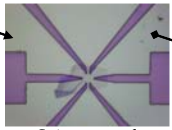
Crossing of pair densiy



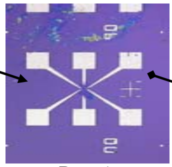
Andreev Reflection Depiction

The Device

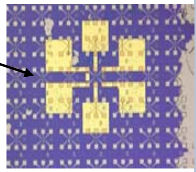
Isolate Sample – Mechanical Cleavage



Spin-coat and develop resist



Deposit Superconducting Electrodes



Ti/Au contact pads

Device Process

- Isolate sample by mechanical cleavage
- Spin-coat resist
  - Develop electrode pattern with mask
- Deposit superconducting electrodes
- Spin-coat resist again
  - Develop pad pattern with mask
- Desposit contact pads
  - Ti(200Å)\Au(1100Å)
- 1µm junction distance.
  - Not a very wide or long junction

The Superconductor[5]:
Au(25Å)\Pb(1070Å)\In(235Å)

Discovered and used in past Josephson junction research for:
- Improved stability and durability
- Controlled grain size
- High Tc (Pb = 84% of mass)
  - ~7.2K

Results and Future

We were able to develop one working device, pictured at left. At room temperature it seemed to behave normally, but at sub-liquid-He temperatures, the device showed problems due to an overbearing ohmic contact. We were unable to make a four-point measurement to try to overcome this, so we are left with undesirable results. In previous devices by K. Konishi, carrier concentrations have been 4.93E+11, and mobilities have been up to 4.83E+4, though the mobilities have been known to decrease with temperature.

Interestingly, even though our measurement temperature was less than a fourth of the electrode Tc, we did not see a supercurrent. Usually the Tc-depression is not so strong.

In future work on the topic, e-beam lithography must be used to make a shorter junction length so the proximity effect can be observed. Varying the length of the channel should eventually be attempted to test the theoretical estimates of the Cooper pair coherence length in Graphene.

1.7K

References

[1] A. Shailos, W. Nativel, et al. arXiv:cond-mat/0612058v2
[2] H.B. Heersche, P. Jarillo-Herrero, et al. *Nature* 446, 56-59 (1 March 2007)
[3] P.R. Wallace. *Phys. Rev.* 71(9), 622-634 (1 May 1947)
[4] M. Wilson. *Physics Today*, 21-23 (Jan. 2006)
[5] W.F. Brucksch, Jr., and W.T. Ziegler. *Phys. Rev.* 62, 348-353 (1942)

Conclusions

Because we were unable to make several devices, the results are as yet inconclusive. The sample we used probably had a low carrier concentration or mobility (as mobilities have already been known to decrease between RT and 77K), and there was a high contact resistance, making it difficult to discern any kind of supercurrent. The estimation that the penetration depth of Cooper pairs in graphene is ~1µm may be supported here as well. A previous study showed widely varying results from sample to sample[2], so work of this type will not be reproducible with precision until a more consistent method to produce graphene is devised.

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