Fabricating Mechanically Adjustable Single Molecule Electrical Contacts

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Abstract:

We investigated the fabrication parameters for mechanically-adjustable break junctions on a phosphor bronze substrate. Mechanically-adjustable break junctions have applications in studying the electron transport of molecules, which could lead to molecule sized circuit components. We have fabricated bridge structures that can be used to form break junctions, were able to measure stable resistances while bending the substrate, and have broken apart and reconnected the break junctions.

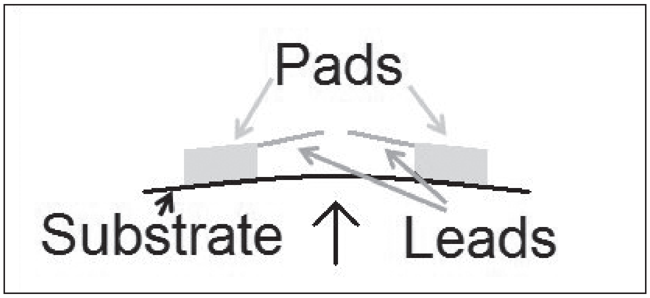

Figure 1: Diagram of break junction.

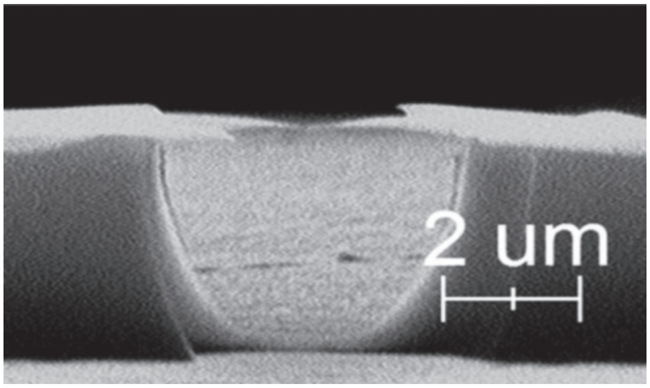

Figure 2: SEM image of bridge (side).

Introduction:

Transistors are approaching a size where it is difficult to make them perform uniformly. Making transistors and other circuit components out of molecules would allow smaller, uniform components, but the electrical properties of the molecules would need to be known. There are many techniques using nanolithography and scanning probe instruments to study the electrical properties of single molecules. Scanning probe instruments are used to take measurements of molecules in solution, but are limited to a temperature range of tens of degrees. Mechanically-adjustable break junctions can be operated at cryogenic temperatures in a vacuum environment [1]. A break junction is formed by pushing up on the substrate, which stretches the bridge until it breaks, forming two leads. Figure 1 shows a schematic diagram of a break junction. Figure 2 shows one of the fabricated bridges from the side in a scanning electron microscope (SEM). The electrical properties of a molecule are examined by trapping a molecule between the leads of the break junction in a known orientation and measuring its resistance.

Ideally, a break junction can be broken and reconnected repeatedly so multiple trials can be run using one device. Our project focused on the fabrication of mechanically-adjustable single molecule break junctions.

Procedure:

The 510 phosphor bronze substrate was polished with 3 μm alumina oxide then diced into a three inch circular wafer with a machine shop shear. The wafer was covered by a layer of MicroSystem's VM652 adhesion promoter then PI2611 polyimide spun at 3,000 rpm. The wafer was raised from room temperature to 310°C over 25 minutes, baked at 310-318°C in air, then allowed to cool with the hot plate for 35 minutes. The photolithography pattern used Futurrex NR7-1500PY resist and had 10 nm of chromium deposited at 2.0 Å per second (Å/s) followed by 80 nm of gold deposited at 5.0 to 6.0 Å/s in a thermal evaporator.

We used a bilayer electron beam resist of MircoChem's MMA 8.5 MAA-EL9 Copolymer, then 950 PMMA-A4; both spun at 3,000 rpm to develop a large undercut. The resist was developed with methyl isobutyl ketone diluted 1:3 with isopropyl alcohol for high resolution. The electron beam lithography pattern had 2.0 nm of chromium deposited at 1.5 Å/s and 80 nm of gold deposited at 5.0 to 6.0 Å/s in a thermal evaporator. The polyimide was etched from underneath the wire using a reactive ion etch.

Many recipes were examined, but the best etch investigated was 80 standard cubic centimeters (sccm) of O_2, 20 sccm CF_4, and 400 watts. The average etch rate for this recipe was 107 ± 15.8 nm per minute for depth and 35.6 ± 5.74 nm per minute for undercut, and the average pressure was 221 milliTorr. (Note: all ± values are sample standard deviations.)

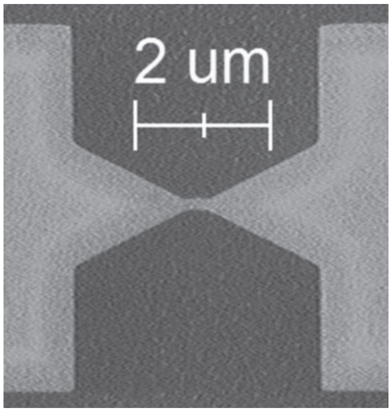

Figure 3: SEM image of bridge (overhead).

Figure 2 shows a bridge right after etching, from the side. Figure 3 shows a bridge from directly overhead. The white lines are the edge of the polyimide on the underside of the gold. The break junctions were formed by bending the substrate in a cryostat with fulcrums pushing down at the ends of the 2.5 cm by 1.0 cm wafer and a screw with a 250 μm pitch pushing from the opposite side.

Results and Conclusions:

The average bridge dimensions were 397 ± 90.2 nm long and 212 ± 64.3 nm wide with the smallest bridge by area being 281 nm long and 112 nm wide. The average resistance was 83.8 ± 7.0 ohms. We were able to load three chips into the cryostat. For each chip, we turned the cryostat screw a quarter turn every twenty seconds until the bridge broke. Due to undiagnosed internal noise, our recording setup would not read any resistances higher than 400,000 ohms, and once the impedance went above 100,000, we knew we had broken the bridge. The first chip we bent had this impedance spike, but did not reconnect as we moved the screw back. It was confirmed broken in the SEM.

The second chip we bent was broken and reconnected twice, then on the third bending, it stayed broken. Figure 4 shows the data from the second bending and reconnection of the second chip. Take note of the breaks in the graph where the data jumped and dropped from 100 ohms to over 100,000 ohms. The last chip bent was broken and did not reconnect as the screw was moved back.

We have concluded that it is possible to make the break junction structures, but several additional tests and adjustments need to be made, including: bending while cooled and under vacuum, automating the bending, refining the sensitivity of the setup to the gigaOhm range, and developing methods for isolating single molecules.

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References:

[1] Martin et. Al.; "Lithographic Mechanical Break Junction for Single-Molecule Measurements in Vacuum: Possibilities and Limitations"; New J. of Physics, 10 No. 6 (2008) <http://www.iop.org/EJ/njp>.

[2] Grüter et. Al.; "Electrical Conductance of Atomic Contacts in Liquid Environments."; Small, 1 No.11, 1067-1070 (2005).

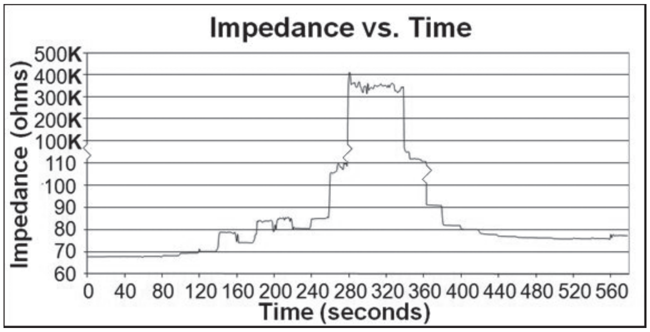

Figure 4: Data from reconnected break junction.