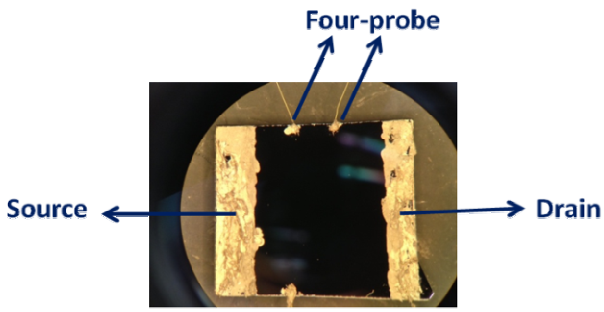
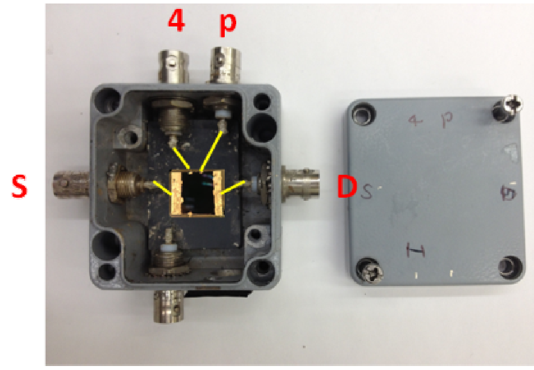
<u>**Four-probe conductivity measurements**</u> **12/19/2013**

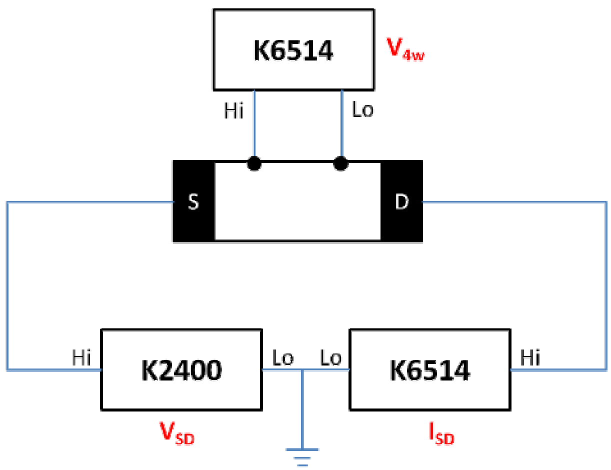


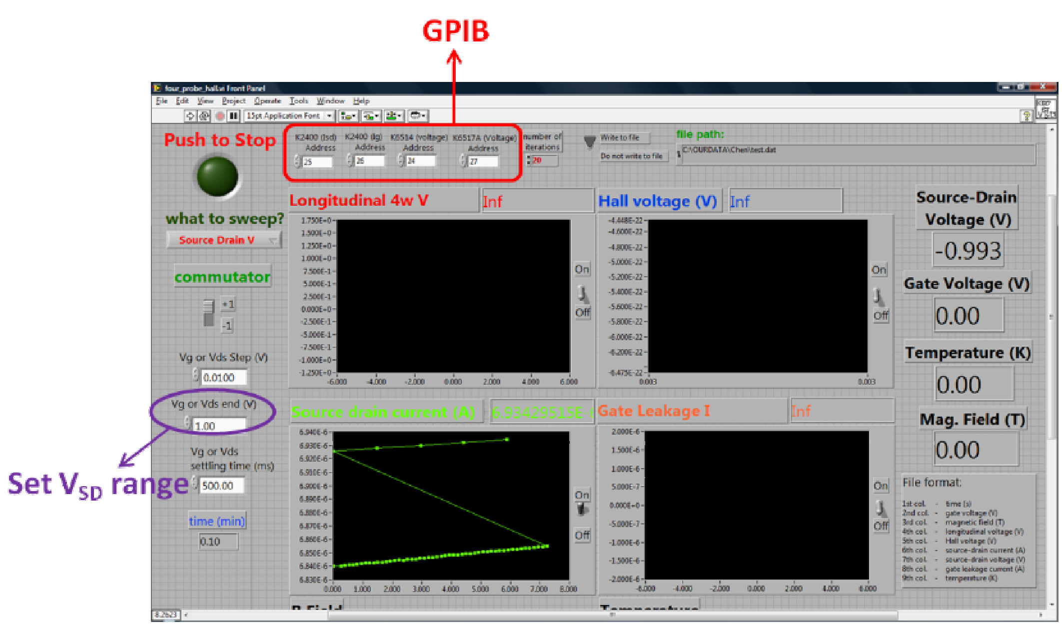

**1. Preparing contacts to your sample.** On a selected sample of a rectangular shape, prepare source and drain (S and D) contacts and two four-probe voltage contacts as shown in the photo above (left). The two voltage probes must be as small as possible (pointed), sitting at the very edge of the channel on the same side and separated by some good fraction of the total channel length. The total channel length, *L*, is the distance between the S and D contacts. The distance between the voltage probes is *D*. *W* is the channel width. The contacts can be painted with a graphite, silver paints or evaporated through a shadow mask, depending on the required study and system. The photo above shows a piece of Si wafer with silver paint contacts as an example.

**2. Sample wiring.** Connect gold wires to each contact and then to BNC pins on the inside of a sample box using silver paint as shown above (right); wait until the silver paint dries, then close the lid tightly. Make sure to label all the connectors/contacts outside the box clearly to avoid confusion.

**3. Electrical wiring. Before connecting any cables to Keithley instruments always make sure that the instruments are Zero-Checked!** Connect a Keithley source-meter (K2400) and two electrometers (K6514) to the sample box using coaxial and triax cables according to the configuration shown below (left). A triax cable is a cable that consists of a high line at the center, a guard (inner sheath) and the ground (the outer braiding), all insulated from each other. In this configuration, both four-probe voltage probes must be floating. To achieve this, use a special triax cable with two BNC connectors on one end and a triax connector on the other (electrometer) end. Connect the voltage probes to the Hi line and the guard of the triax, and then connect the other end of the cable to the electrometer. Make sure that the jumper on the rare panel of this electrometer is <u>disconnected</u>. This jumper, which by default shorts the black and green terminals on the rare panel (shown in the photograph below), essentially connects the guard to the grounded outer braiding of the triax cable. In these 4-probe measurements, the source-meter K2400 supplies a source-drain voltage ($V_{SD}$), one of the K6514 electrometers measures the source-drain current ($I_{SD}$), and the other electrometer measures the four-probe voltage ($V_{4w}$). Make sure to connect the Hi and Lo inputs as indicated in the figure.




**4. Run a LabView program.** **Make sure that there is an <u>appropriate compliance current</u> set on the instruments in the circuit with electrometers. Also make sure that initiating LabView programs will not zero or change the appropriate compliance.** Open the LabView program at "C:\OURDATA\Ying\labview\four_probe_hall.vi". Set up all the parameters (GPIB addresses, sweeping type, sweeping range, file path, etc.) according to the desired measurement. For the four-probe conductivity measurements discussed here, the most important parameter is $V_{SD}$ sweep range. Carefully determine the proper range according to the type of the sample to be tested. The maximum current flowing through the sample (and the electrometer) should not exceed the compliance current, which in turn should not exceed the maximum allowable current through the electrometer (20 mA). Please, check this parameter in the electrometer specifications. The program simultaneously measures $I_{SD}$ and $V_{4w}$ as a function of $V_{SD}$ and writes these data as three columns in a *.dat file.



**5. Data analysis.** Import the recorded data into Origin and use the following equations to calculate 2-probe ($\sigma_{2w}$) and 4-probe ($\sigma_{4w}$) conductivities per square in Siemens ([S] = [$\Omega^{-1}$]), as well as the contact resistance ($R_{con}$) in Ohms. In cases of a negligible contact resistance, $R_{con}$ calculated this way may come out as a small negative value.

$$\sigma_{2w} = \frac{\mathbf{I_{SD}}}{\mathbf{V_{SD}}}\frac{\mathbf{L}}{\mathbf{W}}$$

$$\sigma_{4w} = \frac{\mathbf{I_{SD}}}{\mathbf{V_{4w}}}\frac{\mathbf{D}}{\mathbf{W}}$$

$$R_{con} = \frac{L}{W}\left(\frac{1}{\sigma_{2w}} - \frac{1}{\sigma_{4w}}\right)$$