Influence of the Type of Wetting Layer on the Contact Resistance in Metal-Graphene Ohmic Contacts

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Abstract:

In recent years, graphene has received a lot of attention because of its unique features, such as its high mechanical strength, its unique optical properties and the ultrahigh electron mobility. These unique properties promise a wealth of novel applications and devices. For example, graphene-based ultrathin and ultra-broadband electro-optic modulators, which employ the electrostatic-doping-induced transparency of graphene to create a voltage-controlled optical absorption, have enabled a variety of new applications. The ultra-high carrier mobility also promises transistors with switching speeds well in the terahertz range. However, we must take the evil with the good, as fabricating devices that rely on a single molecular organic layer can be very challenging. One of the main challenges is to fabricate ohmic metal contacts on graphene, as the density of states near the Dirac point is low. High contact resistance in such thin devices can severely degrade the performance. In this study, we focused on the influences of wetting metal layers and doping of graphene on the metal-graphene contact resistance.

Introduction:

Electronic and optoelectronic devices exhibit parasitic capacitance, which, if paired with a series resistance, limits the useful bandwidth of a device. To fabricate ohmic contact on semiconducting materials, it is necessary to avoid a Schottky potential barrier by choosing metal that allows the majority carriers to flow freely in and out of the semiconductor. For graphene, which is typically hole-doped in ambient conditions, this implies that the work function of metal should be higher than the energy gap between vacuum and graphene's Fermi level. In this work we investigated the influence of the contacting metal on the series resistance in graphene devices.

Experimental Procedure:

As shown in Figure 1, silicon wafers were used as both the substrate and the back-gate electrode. A 260-nm-thick aluminum oxide (Al_2O_3) layer was deposited on the wafer by DC reactive sputtering (Target: Al metal, Pressure: 3 mTorr, Argon flow: 32 sccm, Oxygen flow: 1.6 sccm, Deposition rate: 9 nm/min). The breakdown voltage of the Al_2O_3 was measured to determine the allowable range of gating voltages. Monolayer graphene — synthesized by chemical vapor deposition on copper — was then transferred onto the dielectric and patterned by a reactive ion etch. To investigate the effects of adhesion layer on the contact resistance, three metals (10 nm Cr, Ni, and Ti) were used in combination with Al (100 nm). These metal electrodes were thermally evaporated and patterned by a lift-off process.

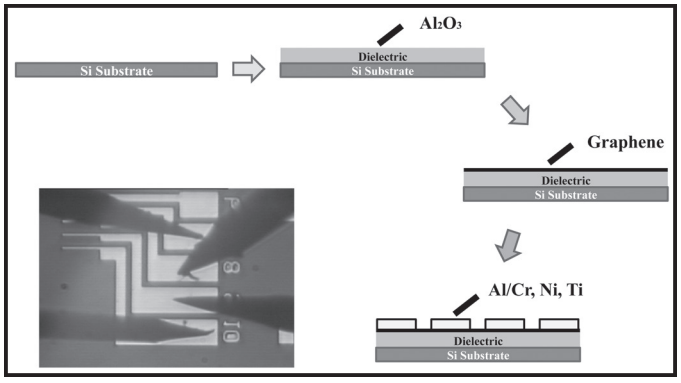

Figure 1: Schematic diagram of the fabrication.

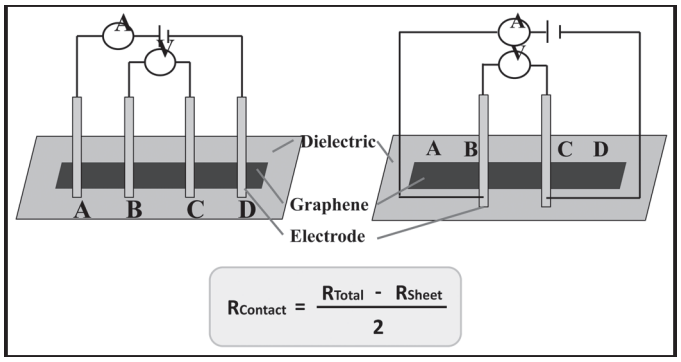

Figure 2: Breakdown voltage measurement.

To measure the contact resistance, a four-point probe method was employed: four electrodes were used to measure the sheet

resistance of the graphene between the inner electrodes (see Figure 2, B and C). Then the two probes were moved from A and D to the inner two contacts (B and C), to measure the total resistance between the metal and the graphene at the contacts. B and C was then given by the difference between these two measured values. Compared to a transmission line method, our method was much less subject to cracks in graphene, and individual pairs of contact resistance could be measured instead of an averaged value.

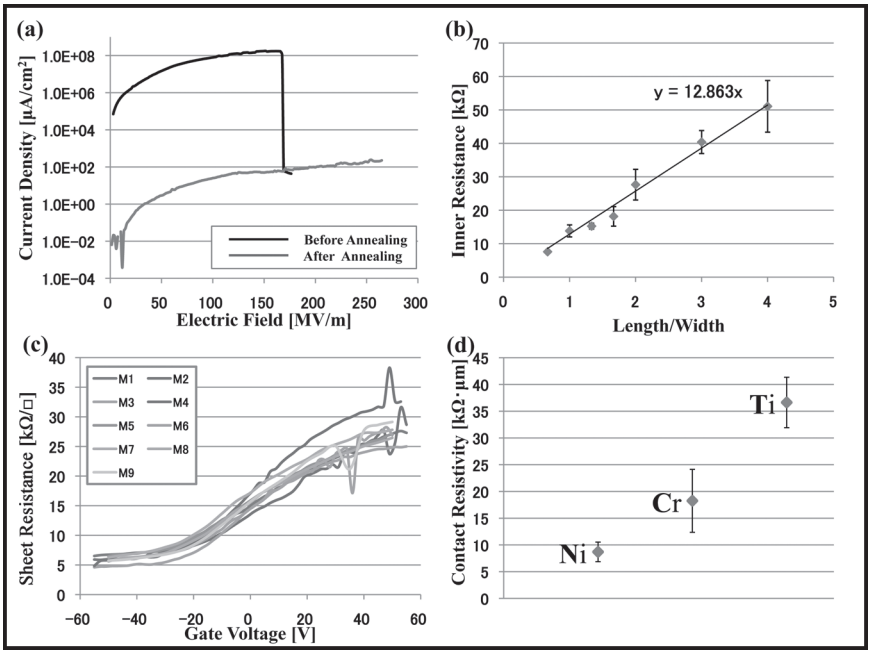

Figure 3: (a) Breakdown voltage of Al_2O_3 before and after annealing the sample at 500°C. (b) The dependence of the resistance of the graphene-bridge vs. the length/width ratio of the graphene between the two center contacts. (c) Influence of the field-gating on the sheet resistance of the graphene. (d) The dependence of contact resistance on types of adhesion layer metals.

Results and Discussion:

Without annealing, the DC sputtered Al_2O_3 layer showed very high leakage currents (see Figure 3a). After annealing the oxide layer at 500°C in H_2 and N_2 atmosphere, the leakage current was significantly reduced and the breakdown voltage was measured to be ~280 MV/m.

Figure 3b shows the dependence of the sheet resistance on the length/width ratio of the graphene. From the slope of the line-fit to the data one can infer that the sheet resistance of the un-gated graphene is 12.8 ± 0.5 kΩ/□.

Figure 3(c) shows the dependence of the sheet resistance on the gating voltage. Field doping effectively changes the sheet resistance between 5 and 28 kΩ/□, for gate voltages of the order of ± 50 V, respectively. The carrier density was calculated to be 9.03×10^{12} cm^2, assuming that the Dirac point is near 55 V.

Figure 3(d) shows the influence of the choice of the metal adhesion layer on the contact resistance. Nickel showed the lowest contact resistance (8.7 ± 1.8 kΩ•μm) of the three, while titanium lead to the highest resistance of 36.6 ± 4.7 kΩ•μm.

Conclusions:

We have shown that aluminum oxide can be deposited by reactive sputtering and, when annealed, can serve as a good dielectric for electric field strength up to 280 MV/m. There was a clear influence of the wetting metal on the contact resistance in the fabricated devices. In particular we found that nickel (ϕ ~ 5.2 eV) provides the lowest contact resistance (~ 8.7 ± 1.8 kΩ•μm) and titanium (ϕ ~ 3.8 eV) led to the highest contact resistance (~ 36.6 ± 4.7 kΩ•μm). Our result is in agreement with the result reported by Giovannetti et al. [1].

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References:

[1] G. Giovannetti, et al., "Doping graphene with metal contacts." Phys. Rev. Lett 101 (2008) 026803