

Characterization of Graphene-Based Interconnects

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Abstract:

Graphene shows a high potential in outperforming copper as the material of choice for next-generation complementary metal oxide semiconductor (CMOS) interconnects. In nanometer-wide channels of the same aspect ratio, graphene is expected to have a higher conductance compared to copper (Cu). Several important factors affect the performance of graphene and need to be explored to showcase its full potential. This project focuses on palladium-graphene contact interaction and the resistivity of graphene interconnects in comparison to Cu. Fabrication of 30 nm wide ribbons is performed via electron-beam lithography followed by a plasma etch to transfer the resist pattern onto graphene. The results show a low contact resistance and no measurable Schottky barrier at the contact. The interconnect resistivity is higher than that of Cu, though close to what is expected at a 30 nm line width.

Introduction:

As the dimensions of integrated circuits steadily decrease, and integrated device speeds improve, copper-wire interconnects place increasingly significant limitations on circuit performance. In addition to reconstruction in systems architecture (e.g. multiple cores) to solve the global interconnect bottleneck, alternatives are being sought to replace copper with a more conductive material. One promising candidate is graphene, a single sheet of sp^2 -bonded carbon atoms. Isolated only four years ago, graphene has already shown extremely high electron mobility at room temperature [1] along with ballistic transport.

On-chip interconnect delay is a bottle-neck for achieving increased chip performance; this problem is only exacerbated with transistor scaling. For 45 nm technology generations and below, size effects in Cu result in increased wire resistivity compared to its bulk value. Thus, there is a high motivation to identify materials and processes to overcome the limitation of Cu interconnects. Graphene nanoribbons (GNRs) are classified as metallic or semiconductor depending on their chirality. Recent conductance models indicate that when line widths are reduced below 8 nm, the resistivity of metallic GNRs levels off while that of Cu wires (with unity aspect ratio) exceedingly rises [2]. This project focuses on the characterization of graphene interconnects. The goals of the project are to (i) extract the contact resistance of palladium to graphene for 30 nm interconnects, and (ii) compare performance (by resistivity) of graphene to Cu interconnects.

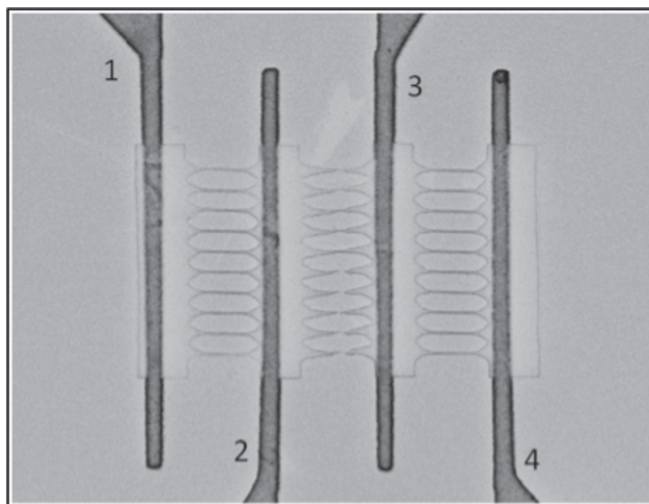


Figure 1: Top view of fabricated graphene channels with Pd/Au contacts.

Experimental Procedure:

Mono and few-layer graphene was deposited onto a 300 nm thermally grown oxide layer (on doped p-type silicon) using a well-known mechanical exfoliation method [1]. The thickness of these graphene flakes was determined by visual contrast as well as atomic force microscopy (AFM).

A JEOL JBX-9300FS electron beam lithography (EBL) system was used to define contacts (1-4, Figure 1) as well as the ribbons in the graphene flake. A metal liftoff process was used to obtain contacts made of palladium (Pd) and gold (Au) and an oxygen plasma was used to etch nanoribbon patterns into graphene. The line widths of the ribbons were in the 30-nm range. Electrical properties were measured at room temperature using an HP4156 Semiconductor Parameter Analyzer.

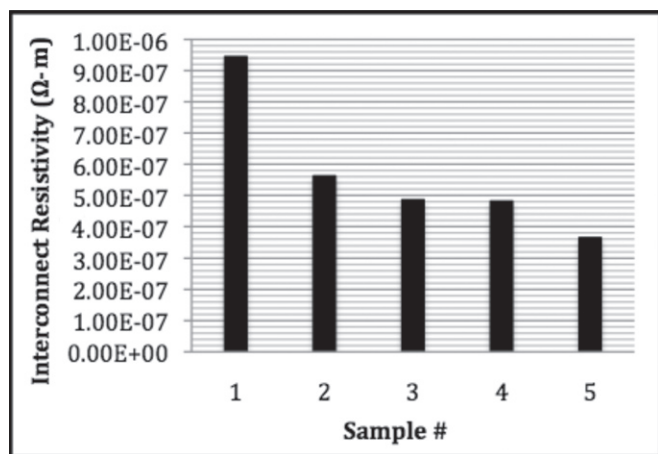


Figure 2: Graphene interconnect resistivity.

Analysis:

The resistivity shown in Figure 2 is that of ten parallel ribbons; this value was determined after subtracting out the contact resistance. A majority of the interconnects exhibited a resistivity less than $50 \mu\Omega\text{-cm}$. The average interconnect resistivity was $71 \mu\Omega\text{-cm}$, with the lowest being $37 \mu\Omega\text{-cm}$. These values are an order of magnitude higher than the bulk resistivity of Cu ($1.72 \mu\Omega\text{-cm}$) and resistivity of narrow Cu wires ($5.0 \mu\Omega\text{-cm}$). Previously reported graphene resistivity in the literature ranges from 0.6 to $200 \mu\Omega\text{-cm}$. The measured resistances are an average of ten parallel ribbons, and variation in individual ribbon line widths and edge effects can contribute to a higher overall resistance. Recent results from the group have shown individual graphene ribbons to have comparable or even lower resistivity as compared to Cu interconnects.

The Pd-graphene specific contact resistance (Figure 3) for the same five samples had a mean value of $6.9 \times 10^{-7} \Omega\text{-cm}^2$, with the lowest being $1.2 \times 10^{-7} \Omega\text{-cm}^2$. Contacts were made to large areas ($3 \mu\text{m} \times 0.2 \mu\text{m}$) to avoid a Schottky barrier. There was no measurable Schottky barrier even down to a few mV. The contact resistance may be further improved by cleaner fabrication and additional annealing.

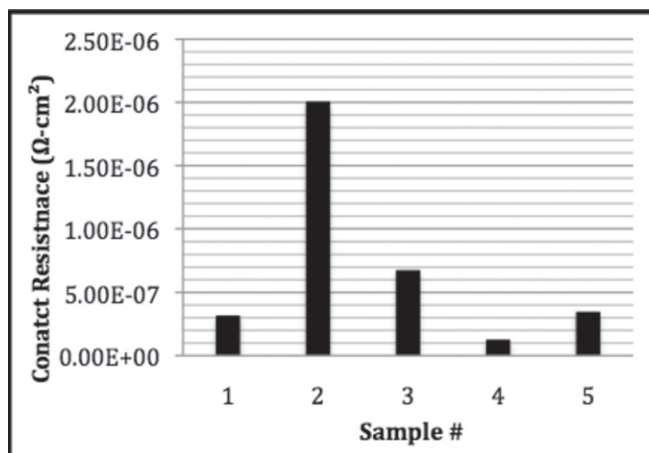


Figure 3: Pd-graphene specific contact resistance.

Conclusions:

For a given sample, the Pd-graphene contact resistance was typically lower than the resistance measured across the corresponding parallel ribbons. On average, the contact resistance accounted for a tenth of the wire resistance. The resistivity of parallel ribbons measured in this experiment was much higher than theoretical projections – theory predicted a resistivity of $0.1 \mu\Omega\text{-cm}$; but the measured values for 1D ribbons were within the range of previously published data for wide graphene ribbons and for 2D graphene.

This experiment concludes that graphene has realistic potential to outperform Cu for next-generation interconnects, though further research that expands upon graphene characterization will be necessary for a definitive conclusion.

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