Lecture 12. Potential Applications of Graphene Nanoribbon (GNR)

The purpose of the lecture: to provide information on the potential applications of graphene nanoribbon.

Expected results: know the potential applications of graphene nanoribbon.

Due to their unique structural and electronic properties, GNRs can have broad range of potential applications. The most apparent is the incorporation of GNRs as reinforcement in polymer hosts for the fabrication of novel high-performance composite materials. Though for such applications bulk production of consistent quality of GNRs is required. One of the major producers of GNRs is Sigma Aldrich with H-terminated GNRs and alkylated GNRs. GNRs have the same high aspect ratio as their parent MWCNTs, but differences in their nanostructure produce unique and unexpected results.

Because of the miniaturization of electronic components, there is a requirement of materials with high permittivity and low loss in the radio and low microwave frequency region. In the high-frequency microwave region, low loss is critical for antennas and other military applications. By varying the type and content of GNRs, the loss and permittivity of composites can be tuned to desirable values over a wide range. The dielectric constant can be tuned from moderate to extremely high (>1000) values, whereas the corresponding loss tangent can be varied from ultralow (<0.02) to high (~1.0). The values are significantly different from that achieved by incorporation of MWCNTs.

Another promising application of GNRs is as an electrode material for batteries and supercapacitors.

In one reference, a unique hierarchical structure composite of graphenewrapped MnO2-GNRs (GMG) was successfully designed and synthesized. In this composite, graphene flakes tightly sandwiched nanosized MnO2 that grew directly on the GNRs. The synthesis of the MnO2-GNRs (GMG) composite has been used as an effective electrode to improve the electrochemical stability for lithium-ion batteries.

Electrochemical experiments demonstrate that GMG exhibits enhanced specific capacity and improved cycling stability as anode materials compared to MnO2–graphene or pure graphene due to synergic effect between the graphene, GNRs, and MnO2. A stable-specific capacity value of 890 mAh/g could be achieved. Moreover, the coulombic efficiency of GMG was maintained at over 99%, excluding the first several cycles.

Polyaniline (PANI)–GNR composite can be used to fabricate a nanocomposite electrode for high-capacity supercapacitors. As shown in Figure 1, PANI nanorods were grown on GNR by the *in situ* polymerization of aniline. In this composite, GNRs not only serve as the substrate to grow the PANI nanorods and improve the electrical conductivity of the composite, but also increase the effective utilization of PANI and enhance the mechanical property of the composite.

The resulting composite has a high specific capacitance of 340 F/g and stable cycling performance with nearly 90% capacitance retention over 4000 cycles. The high performance of the composite is a result of the synergistic combination of electrically conductive GNRs and highly capacitive PANI.

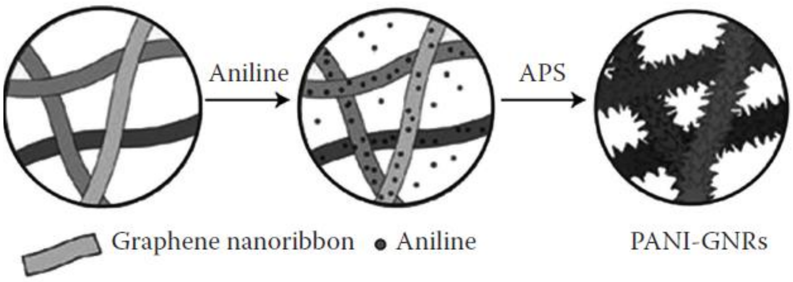

FIGURE 1. Illustration of the synthesis of the PANI–GNRs composite with PANI polymerized directly on the GNRs using APS (ammonium persulfate)

Electronics

Due to their outstanding physical properties, graphene and its allotropes, carbon nanotubes, and graphene nanoribbons are the major candidates to become the silicon of the 21st century and open the era of so-called carbon electronics. Using the property that electrons move like photons could provide the foundation for a new type of electronic device that would capitalize on the ability of graphene to carry electrons with almost no resistance even at room temperature. The property is known as ballistic transport and the electrons in the graphene nanoribbons can move tens or hundreds of micrometers without scattering.

Graphene Transistors

To harness graphene’s electronic and magnetic properties, one must first control the fabrication of GNR of desired width and edge configurations. In particular, graphene-based transistors are being developed rapidly and are now considered an option for postsilicon electronics. Such a revolution was started in October 2004 with the discovery of graphene —two-dimensional sheets of carbon atoms—and observation of the electric field effect in their samples. Major chip-makers are now active in graphene research.

Using graphene nanoribbons, it may be possible to make devices with channels that are extremely thin that will allow graphene FETs to be scaled to shorter channel lengths and higher speeds without encountering the adverse short-channel effects that restrict the performance of existing devices. The FET is the most successful device concept in electronics. The FET is a transistor that relies on an electric field to control the conductivity of a channel of one type of charge carrier in a semiconductor material. According to Moore’s law, the density of integrated circuits double every 18 months and the trend is being followed over the years. Moreover, this size scaling has enabled the complexity of integrated circuits leading to significant improvements in performance and decreases in price per transistor. For decades, making metal-oxide-semiconductor FETs (MOSFETs) smaller in size has been key to the progress in digital electronics. Today, processors containing 2 billion MOSFETs, many with gate lengths of just 30 nm, are in mass production (Figure 2).

However, it is well understood now that MOSFET scaling is approaching its limits, and in the long run it will be necessary to introduce new material and device concepts to ensure that performance continues to improve.

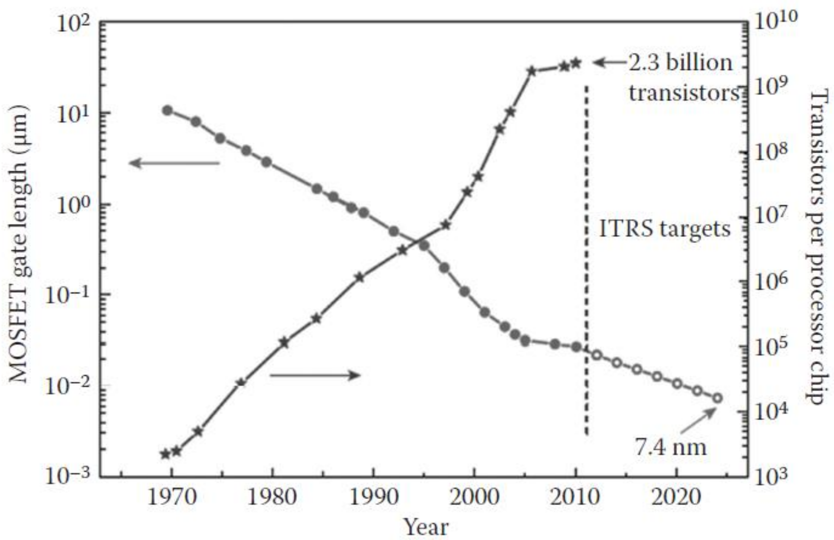

FIGURE 2. Trends in digital electronics. Evolution of MOSFET gate length in production-stage integrated circuits (filled circles) and International Technology Roadmap for Semiconductors (ITRS) targets (open circles). As gate lengths have decreased, the number of transistors per processor chip has increased (stars). Maintaining these trends is a significant challenge for the semiconductor industry, which is why new materials such as graphene are being investigated.