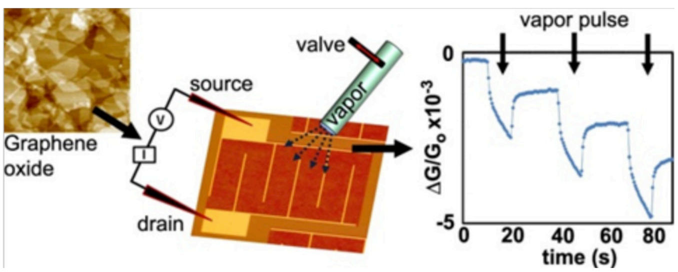
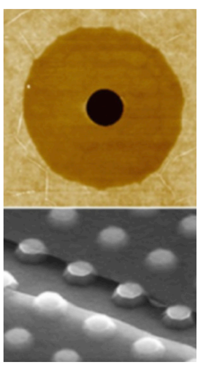
Graphene Materials Research

Large-Scale Graphene Chem/Bio-Sensors

Graphene's atomic thinness makes its electronic properties highly sensitive to adsorbates. ESTD researchers are working on understanding the interaction between molecules and graphene surfaces, together with scalable routes to form practical, state-of-the-art sensors. After developing large-area deposition techniques from solution-exfoliated graphene materials, ESTD researchers have demonstrated chemresistors with parts-per-billion sensitivities to chemical warfare agents.



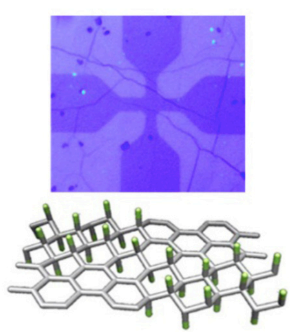
Nanoelectromechanical Graphene Systems (NEMS)



Graphene's high strength (equal to diamond) and low mass are well suited for NEMS sensors and applications. ESTD researchers are developing techniques to broadly engineer mechanical properties of graphene films such as strength, tension, resilience, and quality factors. These materials are being further developed for mass sensors, switches, and filters for RF communications. To date, ESTD research has demonstrated state-of-the-art frequency tunability (>500%) and quality factors (Q~30,000) for graphene-based nanomechanical resonators.

Chemically Engineering Graphene

While graphene's intrinsic properties are unsurpassed, specific applications require modifying its nature. ESTD researchers have discovered and studied new fluorinated graphene derivatives with ideal conjugate properties to graphene; it is highly insulating, transparent, and chemically active. Such fluorographene materials are finding their way into nanoelectronic and sensing applications. ESTD researchers have utilized this idea of fluorine functionalization in the formation of novel graphene nanoribbons, biosensors, and RF transistors.



Graphene in Color: Tunable Optical Absorption

Graphene's single-atom thinness allows it to effectively couple with neighboring surfaces and to other graphene layers. ESTD researchers have developed and studied the electronic and optical interactions between two graphene layers. Two individual graphene sheets hybridize into a new state that gives rise to a narrow absorption band and a "stained-glass window" appearance. This effect is being pursued in optical filtering and optical-based chemical sensing applications.

Magnetotransport in Graphene Devices

Our 13-tesla magnet with variable temperature (2–300 K) and variable angle (2π) rotation allows probing of the unique magnetotransport properties of graphene. Figure (1) shows variable-temperature linear magnetoresistance (MR) that maintains its quantum nature up to nearly room temperature.

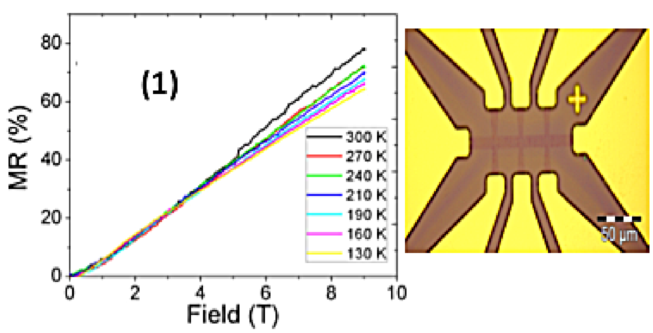
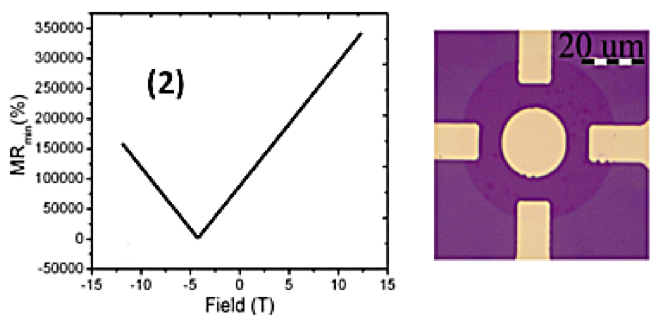


Figure (2) shows the huge increase in the MR (from 80% to 350,000% at 12 tesla) obtained with a metal surface shunt.



These magnetoresistive effects offer the potential for applications in various areas of technology, including magnetic sensors and memory storage devices.

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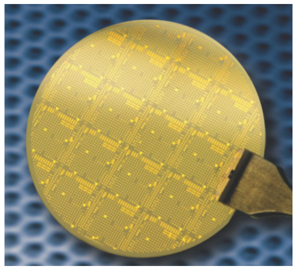
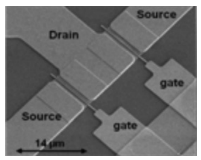
Highly Uniform Wafer-scale Synthesis of Graphene on SiC

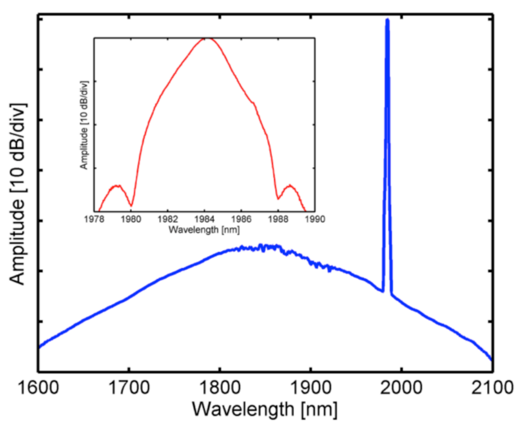


ESTD researchers have determined the critical synthesis parameters for forming graphene on (0001)SiC substrates via Si sublimation (epitaxial graphene); this has resulted in graphene resistivity variations on 100 mm wafers of less than 3%. In addition, working in collaboration with HRL, Inc., under the aegis of the DARPA CERA Program, state-of-the-art 0.25 µm gate length field effect transistors have been fabricated on these wafers using 12 nm HfO_2 gate oxides which exhibit extrinsic f_{max} of 38 GHz. Advanced devices such as mixers operating up to THz frequencies are envisioned.



Graphene Saturable-Absorber Infrared Pulsed Laser

ESTD researchers in collaboration with the Optical Sciences Division have demonstrated a mode-locked laser operating near 2 µm using multilayer graphene as a saturable absorber. The multilayer graphene was synthesized on SiC substrates via Si sublimation and then directly transferred to the optical element (for this case, an Ag mirror), using a process developed and patented by ESTD scientists, producing a wavelength-independent saturable absorber mirror. This approach has the potential to make robust, compact infrared pulsed lasers with broad spectral response for applications such as on-site chemical identification.



Theoretical Models for Graphene FET Operation

ESTD investigators have developed steady-state and RF models for the operation of a graphene-based field effect transistor (FET) that correctly describe the unique characteristics observed in this device, e.g., the V-shaped transfer characteristic. Additionally, the models allow for the direct relation of the device behavior to the underlying physics and the prediction of new device performance. For example, the models predict that a graphene FET is capable of operating at THz frequencies for a properly engineered device. This makes the models extremely valuable tools in developing new advanced devices based on graphene that can impact applications in the THz domain.

Dielectric and Thin Film Integration with Graphene

Graphene integration with dielectrics and other thin films is required to realize various high-frequency devices from field effect transistors to vertical tunneling structures like hot-electron transistors. ESTD researchers have developed a dry functionalization technique, using XeF_2 gas, which creates additional nucleation sites on the otherwise inert graphene surface, enabling ultrathin conformal atomic layer epitaxy or deposition of target films without altering the properties of the graphene. This unique method has been used to deposit uniform III-N films <2 nm thick as well as high-κ gate dielectrics for FET devices on large-area epitaxial graphene. Such techniques are essential to the development of advanced graphene-based devices for THz applications.