Abstract:

Graphene is a single-atom-thick layer of carbon atoms in a honeycomb lattice. It is currently a popular material for study in condensed matter physics and related fields [1-6]. The material has a large number of proposed potential applications including integrated photonic devices. Saturable absorption and photocurrent generation has already been successfully demonstrated [1,2]. We aim to study opto-electronic properties of graphene on a silicon nitride waveguide chip platform. We demonstrate saturable absorption of graphene on a waveguide coupled ring cavity.

Summary:

Graphene has emerged as a novel, zero band gap semiconductor with considerable mechanical strength, electron mobility and optical absorption coefficients. The high potential operation speed for graphene devices encouraged experimental demonstration of vertical incidence metal-graphene-metal (MGM) photodetectors [1]. The high saturable absorption modulation has been used to passively modelock an ultra fast fiber laser [2]. High index contrast silicon-on-insulator and silicon-nitride-on-insulator devices are the next phase for graphene devices.

A single sheet of graphene is a hexagonal lattice with a zero band gap. The dispersion of electrons and holes near the Dirac point is linear. Photo excitation of electrons shifts them from valence band into the conduction band. Sufficient photo excitation will fill the states near the edge of the conduction and valence bands, and impede further absorption [2]. This saturation of states due to Pauli blocking renders the graphene transparent. We aim to integrate graphene with high contrast waveguides on a chip to explore electro-optical and purely optical devices. We aim to observe saturable absorption in graphene by placing graphene in the evanescent field of a waveguide. To achieve sufficient field intensity we will use a high finesse ring cavity. The quality factor of the cavity will be dominated by losses due to graphene absorption. Hence a decrease in absorption will change the quality factor. This can be readily observed by a change in extinction on resonance of a cavity coupled to a waveguide.

Graphene synthesis and processing is actively researched with industrial and academic motivations. Exfoliated crystals from bulk graphite yield the least amount of defects and contaminants in a meticulous and slow process. Wafer scale, and larger graphene sheets have been made with chemical vapor deposition. The later method suffers from higher contamination and defect density.

Complimentary metal-oxide-semiconductor technology has been demonstrated to be suitable for integrated photonic devices and promises high yield and low costs. We have fabricated and tested a silicon nitride ring cavity covered with a graphene flake. We also made coupled cavity and Mach-Zehnder interferometer devices covered with single layer graphene. The graphene is patterned further with metal leads to form MGM type devices.

We used a fabrication flow similar to a previously published device [7], Figure 1. Silicon was thermally oxidized to form a 3.5 µm film. Stoichiometric SiN was deposited with a low pressure chemical vapor furnace in two 235 nm layers. The annealed film was patterned into waveguides and coupled ring cavities with a negative e-beam resist. The nitride was etched in tetrafluoromethane (CF4) chemistry in a plasma etcher. The devices were covered with silicon dioxide. The oxide was planarized and further thinned down with a CF4 etch. Graphene was exfoliated on to a methyl methacrylate resin (PMMA) film and transferred on top of the ring cavity. The flake was patterned with photoresist, and etched with oxygen plasma to control the width, Figure 2.

The waveguide was terminated with inverse tapers [8]. The chip was cut normal to the tapers and the end facets were polished. Light was coupled into the chip with a tapered fiber. Output was collected with a microscope objective. The loss through the chip was 6 db. The width of the waveguide going across the chip was 800 nm and the width of the
waveguide in the ring was 1600 nm. Transmission through the chip was measured with a tuneable laser from 1520 nm to 1620 nm, Figure 3.

The normalized transmission through the device was measured at different input powers. Extinction of transmission is plotted against measured output transmission of the device, Figure 4. Output transmission power is averaged away from the cavity resonance over a 1 nm range. The change in the extinction ratio and hence the cavity losses implies a dependence of the cavity losses on power in cavity. Nonlinear absorption in silicon nitride and silicon oxide is ruled out by repeating the measurements on a cavity without graphene.

The measured saturable absorption shows the feasibility of using graphene as an active material in integrated photonic devices. Graphene coupled to high finesse cavities could be further used for an all-optical switch, as well as a high efficiency detector and modulator.

References:

Figure 1, top: Fabrication process flow; A. SiN (470 nm) deposited on thermal oxide (3500 nm), B. E-beam resist patterning for waveguide and rings, C. SiN etched with CF4 plasma, D. SiO2 deposited over optical structures, E. Oxide planarized, F. Graphene exfoliated and transferred on top of cavity, patterned with photolithography and etched with oxygen plasma.

Figure 2, middle: Atomic force micrograph of patterned graphene flake on top of a ring cavity. Scale bar is 1700 nm.

Figure 3, bottom left: Resonance in the transmission spectrum of a ring cavity covered by a graphene flake.

Figure 4, bottom right: Transmission extinction of a ring cavity with a graphene flake with different input laser power.