Nonreciprocal Graphene Magnetoplasmons: Latest Advances

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***Abstract*—Novel magnetoplasmonic devices including a highly sensitive magnetic sensor based on coupled edge magnetoplasmons, and a graphene ferrite isolator based on the unique TE plasmonic mode of graphene are presented. The magnetic sensor may find application as magnetic reader in magnetic hard drives. The presented isolator is tunable, ultra wideband, and magnetless, and may find applications in terahertz circuits involving nonreciprocal elements.**

I. Introduction

Graphene, a mono-atomic layer of carbon atoms in a honeycomb lattice, with a linear band structure, has spurred huge research interest in recent years due to its unusual properties, such as ultra-high mobility, tunability, ambipolarity [1], [2], and support of exotic surface plasmons [3]. Graphene is the thinnest 2 dimensional electron gas (2DEG). In addition to conventional transverse magnetic (TM) surface plasmons also supported in 2DEGs, graphene also supports transverse electric (TE) surface plasmons. TE surface plasmons propagate in regimes where the interband conductivity dominates over the intraband conductivity [3]. Under a magnetic bias, charges move in cyclotron trajectories and the resulting hybrid (TE-TM) surface plasmons are called magnetoplasmons.

A graphene strip supports an infinite number of surface plasmon modes with transverse resonances across the strip called 2D bulk modes, and two degenerate edge modes. Under a static magnetic bias the degeneracy of the edge modes is lifted and the edge modes exhibit asymmetric dispersion for opposite directions of propagation [4]. This asymmetry was exploited recently for the realization of nonreciprocal magnetoplasmonic devices such as a nonreciprocal phase shifter, a nonreciprocal coupler and a magnetoplasmonic isolator [5]–[8]. In this paper, we present a magnetic sensor based on the nonreciprocity of edge magnetoplasmons, and a magnetless graphene-ferrite isolator exploiting the unique TE plasmons in graphene.

II. Graphene-Ferrite Isolator

The graphene-ferrite isolator is composed of a graphene sheet on a ferrite substrate. The ferrite is biased by a magnetic field parallel to the graphene strip, as shown in Fig. 1. This isolator exploits the TE plasmonic mode of graphene. The magnetic field lines for such a mode are shown in Fig. 1. Any point below the graphene sheet sees clockwise and counter clockwise rotating magnetic fields for opposite directions of propagation. Such counter rotating magnetic fields interact nonreciprocally with the magnetically biased ferrite substrate. As a result the TE plasmon exhibits different amounts of loss for opposite directions. As a result of this nonreciprocity the structure achieves significant isolation.

The proposed isolator is ultra wideband and can be tuned to operate in terahertz, infrared or optical frequencies. Moreover the magnetic field biasing the ferrite can be produced by a longitudinal DC current. Therefore, the structure can operate without a magnet. Finally, this structure presents a configuration where only the TE plasmon mode exhibits nonreciprocity, whereas the TM mode remains reciprocal. Therefore it may be used for experimental demonstration of TE surface plasmons in graphene.

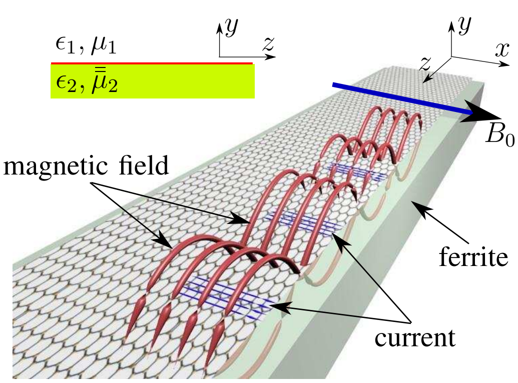

Fig. 1. TE surface plasmons in an infinite graphene sheet on a magnetically biased ferrite slab. The magnetic bias is parallel to the plane of graphene.

III. Magnetic Sensor

The magnetic sensor is composed of two parallel broadside coupled p and n doped graphene strips, shown in Fig. 2. The doping may be applied chemically or electrically. For the magnetically unbiased structure, the two strips have equal scalar conductivities. Therefore, the edge modes propagating on the right (left) edge of the strips exhibit similar dispersion and are phase matched, and hence couple. Under a magnetic bias the conductivity becomes tensorial due to the Lorentz force. However, the p and n doped strips acquire off diagonal conductivities with opposite signs as the magnetic field imparts forces in opposite directions for electrons and holes. In this case, the conductivity seen by the edge modes propagating on the right (left) edge of the strips are different and the edge modes become phase-mismatched, and therefore do not couple. This property can be exploited for the realization of highly sensitive magnetic probes or magnetic readers in magnetic hard drives.

IV. Conclusions

Novel magnetoplasmonic devices including a magnetic sensor based on coupled edge magnetoplasmons, and a graphene ferrite isolator based on the unique TE plasmonic mode of graphene were presented. The magnetic sensor may find application as magnetic reader in magnetic hard drives. The isolator operates without a magnet, is ultra wideband and can be tuned to operate at terahertz, infrared or optical frequencies.

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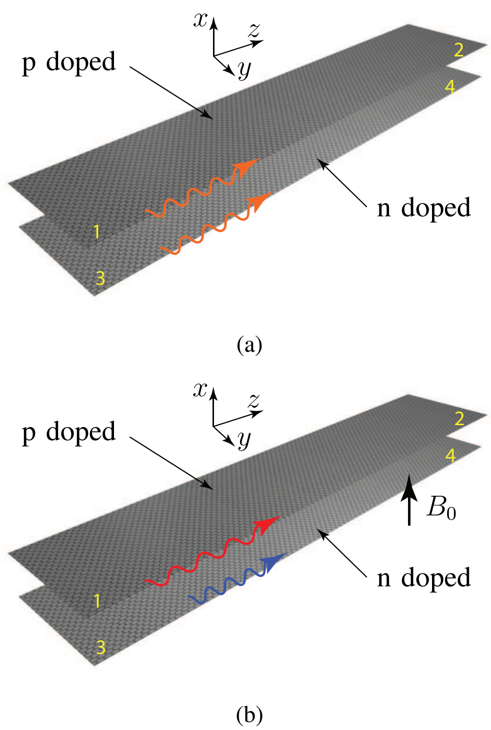

Fig. 2. Magnetically switchable graphene edge coupler consisting of two chemically p- and n-doped broadside-coupled graphene strips. (a) Without any magnetic bias the edge modes exhibit identical dispersions and couple. (b) With magnetic biasing the edge modes become phase-mismatched and do not couple.

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