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On-chip terahertz spectroscopy of magnetoplasmons in a two-dimensional electron gas

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***Abstract*— We report observations of magnetoplasmons at frequencies up to 400 GHz in gated two-dimensional electron gases (2DEG) at low temperature (~ 2K). We observed bulk magnetoplasmons for frequencies greater than the cyclotron resonance frequency, and attributed resonances occurring at frequencies below the cyclotron resonance to formation of edge magnetoplasmons (EMPs). Our full-wave 3D electromagnetic simulation results are in good agreement with the experimental findings, allowing us to predict the spatial distribution of both bulk and edge magnetoplasmon modes in the 2DEG.**

I. INTRODUCTION

Obtaining the plasmonic response of mesoscopic systems at low temperatures (<4K) is difficult for many existing near field broadband microscopy techniques. We have recently shown that on-chip THz-TDS spectroscopy is possible on an integrated chip containing both a 2DEG and regions of LT-GaAs, the latter for signal THz signal excitation and detection, with a coplanar waveguide (CPW) linking the two regions [1].

Magnetoplasmons are plasmons coupled to cyclotron resonances driven by a magnetic field. We reported the evolution of bulk THz magnetoplasmon resonances as a function of a magnetic field in earlier work [2]. Here, we perform on-chip THz on-chip spectroscopy in magnetic field on a simpler rectangular 2DEG mesa, allowing both bulk and edge magnetoplasmons to be observed, and compare our experimental results to theoretical predictions.

II. RESULTS

Figure 1(a) shows a schematic of the experiments. We measure the signal transmitted through the 2DEG channel by photoconductive (PC) detection. Figure 1(b) shows an optical image of the fabricated device containing three plasmonic coupled cavities formed from regions of gated and ungated 2DEG in series (two ungated cavities: C1, and C3, and one gated: C2). To investigate the magnetoplasmons in the 2DEG channel in a magnetic field, we measured gate-modulated (GM) signals transmitted through the 2DEG as a function of the magnetic field in the range of 0–0.8 T; THz pulses were generated at a PC switch S1, passing through the 2DEG before being detected at PC switch S3. Figure 1(c) shows an FFT of the measured GM signals as a function of the magnetic field when with a static gate bias (V_g) of -3.1 V. Four plasmonic resonances are observed at B = 0 T; at frequencies of 57 GHz, 132 GHz, 215 GHz, and 269 GHz, corresponding to the first, second, third, and fourth order plasmonic resonances in the gated channel, respectively. As we increase the magnetic field, magnetoplasmons form as plasmon resonances couple to the cyclotron resonance. The bulk magnetoplasmon resonance frequency (f_{mp}) can be expressed by the following equation: $f_{mp}{}^2 = f_p{}^2 + f_c{}^2$, where f_p is the plasmon frequency at B = 0, and f_c is the cyclotron frequency, given by $f_c = eB/2\pi m^*$, where m^* is the effective electron mass. The black lines in Fig. 1(c) are the calculated bulk magnetoplasmon resonances in the gated cavity and f_c is shown as red line. We also observed resonances occurring at frequencies lower than the cyclotron resonance frequency (red line), which indicates formation of EMPs. EMPs are collective excitations of the 2DEG formed as a result of the Hall current flowing in the 2DEG channel which pushes plasmons to the edge of the 2DEG. The frequency of observed resonances for both bulk magnetoplasmons and EMPs agrees well with our full-wave simulation results as shown in Fig 1(d). Our simulation results also predict the spatial distribution of plasmons modes in the 2DEG channel, thus allowing us to distinguish between bulk and EMPs.

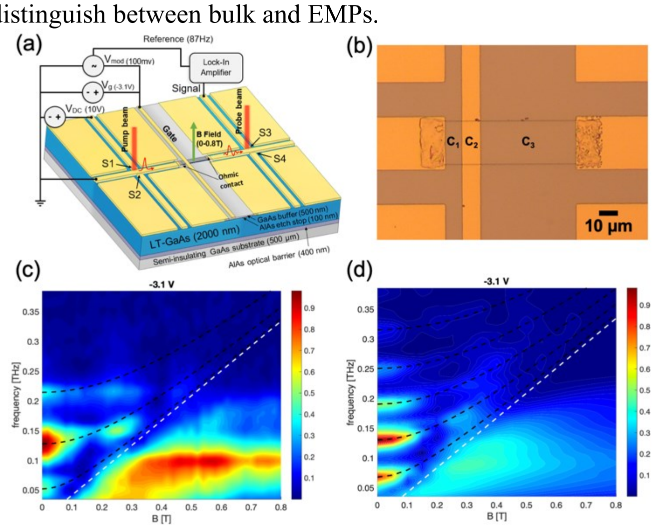

Fig. 1. (a) Schematic of on-chip THz spectroscopy for observation of magnetoplasmons in a 2DEG channel integrated into the CPW. (b) An optical image of the 2DEG channel and CPW. Color-scale plot of the FFT amplitude for gate-modulation signals plotted as a function of frequency and magnetic field for V_g = -3.1 V in (c) experiment and (d) simulation. The white line is the calculated cyclotron resonance frequency and the dashed black lines are the predicted magnetoplasmon resonance frequency

III. SUMMARY

We report evolution of EMPs in a 2DEG in low-THz frequency region (up to 400 GHz) and as a function of magnetic field. Our experimental findings are in good agreement with full-wave 3D electromagnetic simulation results which predict EMP modes in the 2DEG.

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