Investigation of two-dimensional plasmons in grating-gated AlGaN/GaN heterostructures with terahertz time domain spectrometer

D. Pashnev, T. Kaplas, V. Korotyeyev, V. Janonis, I. Grigelionis, A. Urbanowicz, J. Jorudas, S. Indrišiūnas, N. Alexeeva, and I. Kašalynas
THz photonics laboratory, Center for Physical Sciences and Technology, Vilnius, 10257 Lithuania

***Abstract*— Two-dimensional (2D) plasmons in grating-gated AlGaN/GaN heterostructures were investigated by terahertz time domain spectroscopy observing the distinctive minima and inflection points in the transmission amplitude and phase spectra, respectively. The main features of 2D plasmons at temperature of 80 K were the fundamental mode position at 2.2 THz (grating period of 600 nm, filling 50 %), the quality factor up to 8 and the modulation of transmission amplitude and phase up to 50 % and 18 deg, respectively (period 1000 nm, filling 80 %).**

I. INTRODUCTION

ELECTRICAL robustness and high electron mobility make III-nitride heterostructures an excellent candidate for the development of plasmonic terahertz (THz) devices [1, 2]. Excitation of 2D plasmons in grating-gated heterostructures has been mainly studied by a Fourier transform infrared spectroscopy [2,3]. Meanwhile, THz time domain spectroscopy (TDS) is a powerful tool used to investigate material properties (complex dielectric constant and refractive index dispersion) by measuring both the power and phase spectra in transmission and reflection geometry [4].

II. RESULTS

In this work, the power and phase spectra of THz pulses passing through the grating-gated two-dimensional electron gas (2DEG) in AlGaN/GaN structures were investigated by using THz TDS spectrometer (T-SPEC 800, TeraVil) in the frequency range of 0.1-4 THz. The periodic metal grating on area of 2x2 mm was processed and used for efficient THz radiation coupling with 2DEG plasmons. The period and the filling factor of the grating was selected from a set of 600, 800, and 1000 nm and 50 and 80 %, respectively. A liquid nitrogen cryostat was used to perform measurements in the temperature range of 80–300 K. The THz pulse transmitted through the empty and with the sample cryostat was acquired in order to find the power and phase spectra.

Resonant excitation of the 2D plasmons was experimentally observed for all grating-coupled samples within the frequency range of 1-3 THz. Typical results are shown in Fig. 1. The resonance features were perceived as the emergence of distinctive minimum and inflection point in the transmission amplitude and phase spectra, respectively. In the case of filling factor 50 %, the change of grating period from 1000 to 600 nm shifted the resonance position from 1.4 THz to 2.2 THz. The latest was the largest value of fundamental mode of 2D plasmons observed in AlGaN/GaN heterostructures so far [5]. The sample with grating period of 1000 nm and filling 80 % demonstrated more obvious resonance features in both amplitude and phase spectra at 1.4 and 2.6 THz corresponding to the excitation of the first and second order resonance modes. The first modulated the transmission amplitude and phase values up to 50 % and 18 deg, respectively. The 2D plasmons were observed up to room temperature demonstrating the quality factor values up to 8. Comparative analysis of amplitude and phase spectra revealed that the phase signal was less sensitive to the defects of the grating-coupler [5].

The resonant features were also simulated in the framework of the rigorous solution of the Maxwell equations [6]. Comparison of theoretical and experimental results allowed us to link resonance parameters of 2D plasmons with the electron density, mobility, and effective mass of 2DEG in AlGaN/GaN heterostructures.

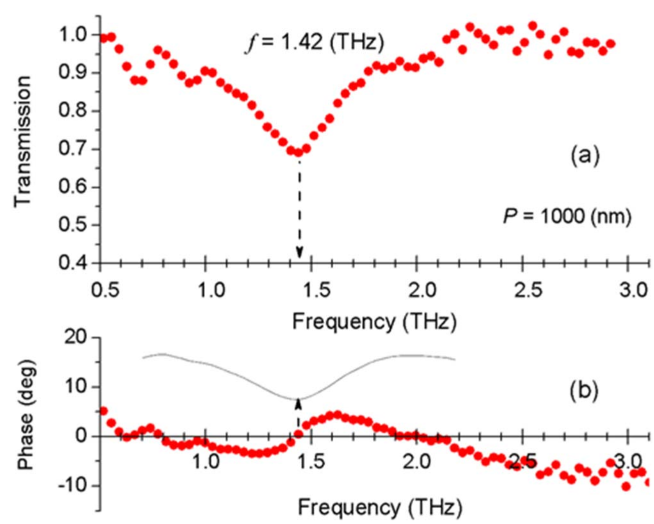

Fig. 1. Transmission (a) and phase (b) spectra of the 2D plasmons in grating-gated AlGaN/GaN heterostructure at 80 K. The filling factor and grating period is 50 % and 1000 nm, respectively. Observed at frequency of 1.42 THz, the 2D plasmons modulated the transmission amplitude and phase values up to 30 % and 8 deg, respectively.

REFERENCES

[1] M. Bauer et. al., A high-sensitivity "AlGaN/GaN HEMT terahertz detector with integrated broadband bow-tie antenna," *IEEE Trans. Terahertz Sci. Technol.*, vol. 9(4), pp. 430-440, 2019.

[2] V.A. Shalygin et. al., "Selective terahertz emission due to electrically excited 2D plasmons in AlGaN/GaN heterostructure," *J. Appl. Phys.*, vol. 126, pp. 183104-1-11, 2019.

[3] A.V. Muravjov et. al., "Temperature dependence of plasmonic terahertz absorption in grating-gate gallium-nitride transistor structures," *Appl. Phys. Lett.* vol. 96, pp. 042105-1-3, 2010.

[4] I. Pupeza R. Wilk and M. Koch, "Highly accurate optical material parameter determination with THz time-domain spectroscopy," *Opt. Express,* vol. 15(7), pp. 4335-4350, 2007

[5] D. A. Pashnev et. al., under submission *Appl. Phys. Lett.*, 2020

[6] V.V. Korotyeyev et al, "Interaction of sub-terahertz radiation with low-doped grating-based AlGaN/GaN plasmonic structures. Time-domain spectroscopy measurements and electrodynamic modeling," *SPQEO,* vol. 22(2), pp.237-251, 2019