THz emission from grating-coupled AlGaN/GaN heterostructures: comparison between plasmonic and thermal emission

I. Kašalynas[1], R. Venckevičius[1], V. Jakštas[1], V. Janonis[1], J. Laužadis[1], G. Seniutinas[2], E.Širmulis[1], G. Valušis[1], K. Požela[1], S. Juodkazis[2], P. Prystawko[3], and M. Leszczyński[3],
[1]Center for Physical Sciences and Technology, A. Gostauto 11, LT-01108 Vilnius, Lithuania
[2]Swinburne University of Technology, John St. Mail H34, Hawthorn, VIC 3122, Australia
[3]Institute of High Pressure Physics UNIPRESS, Sokołowska 29/37, 01-142 Warsaw, Poland

***Abstract*— The THz emission from large-area-grating coupler placed on the 2DEG AlGaN/GaN heterostructures was measured at frequency range 0.3-30 THz and temperature from 300 to 500 K with high spectral accuracy. The THz emission spectrum below 10 THz was found to be close to the thermal black-body radiation. Indistinct radiation modified with 2DEG plasma resonances was observed at frequencies below 3 THz.**

I. INTRODUCTION

THE application of terahertz (THz) radiation in security and medical diagnostics besides sensitive THz detectors also requires development of the compact high power THz emitters operating at room temperature [1-4]. High up to 1.8 μW power emission with power conversion efficiency of 1.6×10^{-6} in the range of 0.5-4.0 THz have been reported from AlGaN/GaN field effect transistors (FETs) with sub-micron grating Ohmic contacts [1]. Later substantially smaller power radiation was reported by submicron gate size HEMT demonstrating, for the first time, the emission peak tunability by the gate voltage between frequencies 0.75 and 2.1 THz [2, 3]. However Ohmic grating approach was abandoned and many groups worked with the THz plasmonic emitters based on FETs with Schottky gate couplers [4].

On the other hand, the properties of electron plasma and lattice oscillations have been widely investigated in polar semiconductors and heterostructures such as GaAs and InGaAs [5], and GaN and AlGaN alloys [6-7]. Recently thermally stimulated selective THz emission from heavily doped GaAs and AlGaAs semiconductors have been observed at frequencies of coupled oscillations of free electron plasma and optical phonons but without the grating coupler [7].

In this work, the THz emission from the grating coupled AlGaN/GaN heterostructures with two dimensional electron gas (2DEG) was investigated in the wide frequency range up to optical phonons frequencies. The metal grating of 2 x2 mm^2 size and the period from 0.2 μm to 150 μm were positioned on top of heterostructure using the electron beam and standard ultraviolet photolithography with the thin metal films deposition facilities. The Ohmic contacts were processed of appropriate ratio of Ti/Al/Ni/Au metals stack annealing at optimized temperature in N2 for 30s. After the metals Ni/Au were used to form HEMT with Schottky type electrodes [7].

The reflection and emission spectra of the HEMT with large area grating coupler were obtained by the Fourier transform infrared (FTIR) spectrometer (Nicolet 8700, Thermo Scientific) and the custom designed FTIR spectrometer with vacuum option both equipped with the polarization optics. Absolute emission power was measured with the calibrated THz power meter (Thomas Keating). The THz radiation spectrum from the heterostructure without the grating coupler was also measured under the same conditions and was later used as the reference. The spectra were measured at frequency range 10-1000 cm^{-1} (0.3-30 THz) with the accuracy of 1 cm^{-1} and temperature up to 500 K.

Comparative analysis of the emission spectra from the AlGaN/GaN heterostructure with and without grating revealed a polarization dependent THz emission. The THz emission spectrum below 10 THz was close to the thermal black-body radiation spectrum. Indistinct radiation modified with 2DEG plasma resonances was measured only for the small period grating couplers and it was observed in frequency range below 3 THz. Measured absolute power values demonstrated that the grating coupled AlGaN/GaN emitters was able to provide electrical-to-optical conversion efficiency of about 10^{-3} in a frequency range below 10 THz.

REFERENCES

[1] T. Onishi, T. Tanigawa and S. Takigawa, "*High power terahertz emission from a single gate AlGaN/GaN field effect transistor with periodic Ohmic contacts for plasmon coupling*", Appl. Phys. Lett. **97**, 092117 (2010).

[2] A. El Fatimy, N. Dyakonova, Y. Meziani, T. Otsuji, W. Knap, S. Vandenbrouk, K. Madjour, D. Théron, C. Gaquiere, M.A. Poisson,, S. Delage,, P. Prystawko, and C. Skierbiszewski, "*AlGaN/GaN high electron mobility transistors as voltage-tunable room temperature terahertz sources*," J. Appl. Phys. **107**, 024504 (2010).

[3] W. Knap, S. Nadar, H. Videlier, S. Boubanga-Tombet, D. Coquillat, N. Dyakonova, F. Teppe, K. Karpierz, J. Łusakowski, M. Sakowicz, I. Kasalynas, D. Seliuta, G. Valusis, T. Otsuji, Y. Meziani, A. El Fatimy, S. Vandenbrouk, K. Madjour, D. Théron, Ch. Gaquière, "*Field effect transistors for terahertz detection and emission*," J. Infrared Millim. Terahertz Waves **32**, 618-628 (2011).

[4] T. Otsuji, T. Watanabe, S.A. Boubanga Tombet, A. Satou, V. Ryzhii, V. Popov, and W. Knap, "*Emission and detection of terahertz radiation using two-dimensional plasmons in semiconductor nanoheterostructures for nondestructive evaluations*," Optical Engineering **53**(3), p. 031206 (2014).

[5] J. Ibáñez, Enver Tarhan, A. K. Ramdas, S. Hernández, R. Cuscó, L. Artús, M. R. Melloch, and M. Hopkinson, "*Direct observation of LO phonon-plasmon coupled modes in the infrared transmission spectra of n-GaAs and n-$In_xGa_{1-x}As$ epilayers*," Phys. Rev. B **69**, 075314 (2004).

[6] D.N. Talwar, "*Direct evidence of LO phonon-plasmon coupled modes in n-GaN*," Appl. Phys. Lett. **97**, 051902 (2010).

[7] N. Rahbany, M. Kazan, M. Tabbal, R. Tauk, J. Jabbour, J. Brault, B. Damilano and J. Massies, "*Measurement of the effect of plasmon gas oscillation on the dielectric properties of p- and n-doped $Al_xGa_{1-x}N$ films using infrared spectroscopy*," J. Appl. Phys. **114**, 053505 (2013).

[8] K. Požela, E. Širmulis, I. Kašalynas, A. Šilėnas, J. Požela, and V. Jucienė, "*Selective thermal terahertz emission from GaAs and AlGaAs*," Appl. Phys. Lett. **105**, 091601 (2014).

[9] V. Jakštas, I. Kašalynas, I. Šimkienė, V. Strazdienė, P. Prystawko, and M. Leszczynski, "*Schottky diodes and high electron mobility transistors of 2DEG AlGaN/GaN structures on sapphire substrate*," Lith. J. Phys. **54**, 227-232 (2014).