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Raman Spectroscopy Used to Assess the Temperature and Mechanical Stress in Thin Films of Microelectronic Structures

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Abstract:
In this experimental work we examined the temperature and mechanical stress in the thin films of microelectronic structures based on GaN and AlN by Raman spectroscopy. The rise in temperature in the Raman spectrum is shown by shifting the Raman bands toward lower wavenumbers. Similarly like with changes of temperature, the changes of the positions of Raman bands may indicate the changes of mechanical stress in the structure. It was confirmed experimentally that in the case of tensile stress the Raman bands are shifted towards lower wavenumbers, and under compressive stress to higher wavenumbers.

INTRODUCTION

Multilayer structures are widely used in microelectronics. Thin films of on silicon substrates are employed as insulating, passivating, tunnelling and interference layers. It is difficult to determine experimentally the magnitudes of physical quantities inside the microelectronic structures. In a series of experiments, Raman spectroscopy enabled us to assess the temperature and mechanical stress in the thin films of microelectronic structures based on GaN and AlN. The reason for using Raman spectroscopy is the advantage provided by a confocal microscope focusing a laser beam exciting the sample. The lateral resolution is given by the diameter of the laser beam. When using a red He-Ne laser, the diameter is approx. 1 µm. The depth resolution depends on the penetration depth of the exciting light into the material, thus on its wavelength, on the optics used and on the optical properties of the material under study.

EXPERIMENTAL

The structures were examined by a Raman spectrometer JobinYvon Labram 300 equipped with a confocal microscope Olympus BX-40, He-Ne excitation source (633 nm) and a grid monochromator (1800 grooves/mm). The monochromator and confocal slits were fully open (200 µm and 1000 µm, respectively). The Raman spectrometer was calibrated with respect to the diamond band (1333 cm^{-1}) and silicon band (520.7 cm^{-1}).

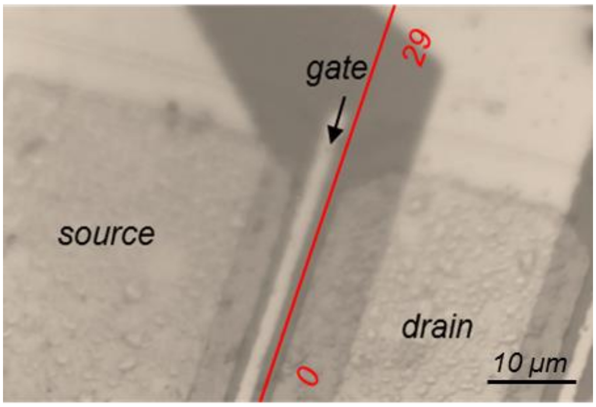

Fig. 1:
Optical micrograph showing the channel of the HEMT with indication of the direction and number of steps during Raman scanning analysis (30 steps).

RESULTS AND CONCLUSION

Assessment of local temperature

The temperature dependence of the positions of Raman bands was used to assess the local temperature in the channel of a HEMT based on AlGaN/GaN deposited on a SiC substrate. For a proper performance of the transistor it is crucial to know the mechanism of heat transfer and to locate its source. Heat stems from local losses at the edge of the gate from the side of the drain. When assessing the temperature along the channel we monitored the position of the E_2^H Raman band of GaN. The layer of GaN had a thickness of approx. 2 µm. At room temperature (T=300 K) the band is centred at 567.5 cm^{-1}. Figure 1 is an optical micrograph of the channel of HEMT with indicated number of the steps and direction of scanning by Raman spectroscopy. The transistor is heated to different temperature depending on the voltage V_{DS} applied between the drain and source and on whether a cooler was used or not. For instance, for V_{DS}=24 V the E_2^H band is centred at 564 cm^{-1}, which corresponds to a temperature of 480 K, whereas for V_{DS}=15 V and used cooler the band is located at 566 cm^{-1}, which corresponds to 400 K [1]. Mapping revealed that the whole chip had the same temperature. This contradicts the assumption of a steep temperature decrease in the direction away from the channel. Nevertheless, the measured and simulated values of temperature in the channel were the same.

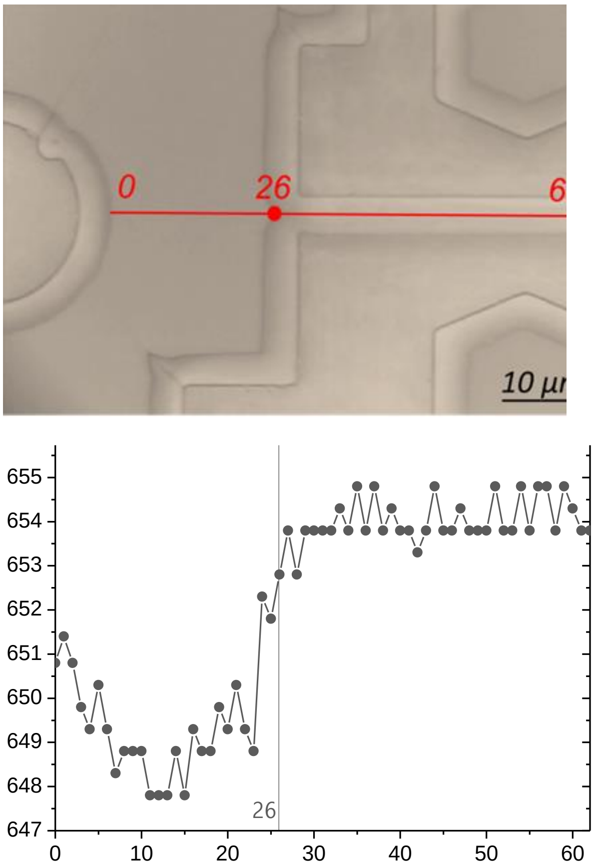

Fig. 2:
Etched AlN micromechanical cantilever on a Si substrate with indication of the direction and of the number of steps in Raman scanning analysis (top figure). Variation of the centre of the E2 Raman band of AlN due to the presence of mechanical stress in dependence on the position of the focused laser beam (bottom figure).

Assessment of mechanical stress

Deposition of thin layers on substrates of different composition and subsequent technological operations introduce mechanical stress into the structures. In micromechanical structures the total mechanical stress may exceed the ultimate strength and the structure gets destroyed. Similarly like with changes of temperature, the changes of the positions of Raman bands may indicate the changes of mechanical stress in the structure. It was confirmed experimentally that in the case of tensile stress the Raman bands are shifted towards lower wavenumbers, and under compressive stress to higher wavenumbers. In the case of thin AlN films in equilibrium (relaxed) state the E_2 Raman band is centred at ≈657 cm^{-1} [2-4]. Figure 2 (top) shows an etched AlN cantilever on a Si substrate. The bottom graph is the result of linear scanning illustrating the shift of the characteristic E_2 Raman band towards lower wavenumbers revealing the presence of tensile stress in the axis of the cantilever.

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REFERENCES

[1] Ming S.L., Bursill L.A., Prawer S., Nugent K. W.: Temperature dependence of Raman scattering in single crystal GaN films, Appl. Phys. Lett., Vol. 74, No. 21, 3125-3127 (1999), http://dx.doi.org/10.1063/1.124083

[2] Lughi, V., Clarke, D. R.: Defect and stress characterization of AlN films by Raman spectroscopy, Applied Physics Letters 89 (2006) 241911, http://dx.doi.org/10.1063/1.2404938

[3] Tran, A.T., Wunnicke, O., Pandraud, G., Nguyen, M.D., Schellevis, H., Sarro, P.M.: Slender piezoelectric cantilevers of high quality AlN layers sputtered on Ti thin film for MEMS actuators, Sensors and Actuators A: Physical 202 (2013) 118-123, DOI: 10.1016/j.sna.2013.01.047

[4] Kuball M.: Raman spectroscopy of GaN, AlGaN and AlN for process and growth monitoring/control, Surf. Interface Anal. 31, (2001) 987–999, DOI: 10.1002/sia.1134