2D Micro-Raman mapping of thermomechanical local stress in assembled GaN LEDs and Si chips

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Enrico Brugnolotto[1], Claudia Mezzalira[1], Fosca Conti[1], Danilo Pedron[1,2] and Raffaella Signorini [1,2,*]

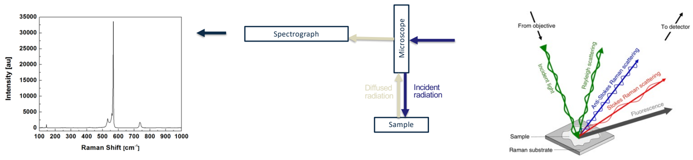
Università degli Studi di Padova

[1]Department of Chemical Science, University of Padova, Via Marzolo 1, I-35131 Padova, Italy
[2]Consorzio INSTM, Via G. Giusti 9, I-50121, Firenze, Italy

Overview

✓Light emitting devices, or LEDs, are extensively studied in terms of emission efficiency, wavelength modulation and stability and duration, as they are widely used for applications in various fields: for interior lighting and exteriors, of both computer and smartphone screens and for the automotive industry.
✓Gallium nitride (GaN)-based LEDs are particularly interesting for applications in the visible range and for the realization of white emitting devices.
✓The creation of these microelectronic devices requires the use of materials with different chemical-physical characteristics which are interfaced through very specific and optimized interconnections.
✓They inevitably induce stresses inside the devices, which affect their final performance. The possibility of measuring and quantifying the degree of induced stress favours the identification of assembly processes with a lower impact, directing the processes towards the realization of more performing devices.
✓This work focuses on the analysis of the stress induced in the GaN emissive layer by the assembly process, as a function of assembly parameters such as the support material, and the applied pressure. In parallel, the investigation on Si chips, which are used as a substrate for the deposition of GaN LEDs, allows to obtain additional information on the origin of stress development.

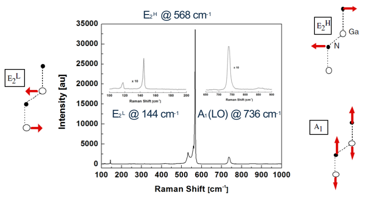
✓When a light beam goes through a sample a fraction of it is scattered in all directions.
✓The main component of the scattered light is Rayleigh scattered, an elastic process that results in a radiation of the same wavelength of the incident light.

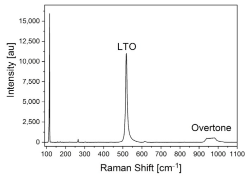


✓A small portion of the scattered light, however, undergoes Raman scattering, an inelastic process that sees some of the energy being ceded to the sample.
✓Raman scattered light therefore holds important information about the vibrational levels of the substance that is being examined.

Stress Determination

✓GaN presents two E_2 phonon peaks and LO phonon peak Raman active





✓ Si presents an intense Raman signal with full width at a half maximum of ca. 8 cm^{-1}, centred at ~520 cm^{-1}, and corresponding to the zone-center (q = 0) optical phonon O(Γ), and a broad peak at 950 cm^{-1}, the second order Raman signal.
✓The position of the GaN E_2H and Si LTO phonon modes are strictly related to temperature, stress and electric field and will reflect the presence of local lattice stresses, induced during the assembling process.
✓It is possible to evaluate the local stresses induced during the assembling process, using a linear dependence of the Raman shift to the average value of the total induced "in-plane stress", through the biaxial stress coefficient:

$$\Delta\omega_{E_2^H} \approx K\,\frac{(\sigma_{xx}+\sigma_{yy})}{2} + A\,\Delta T$$

$(\sigma_{xx} + \sigma_{yy})/2$ in-plane stress, K biaxial stress coefficient, A temperature coefficient , ΔT temperature rise

Bagnall et al. [2017] $K = -3.3\pm0.1\ cm^{-1}/GPa$ and $A = 0{,}014\ cm^{-1}K^{-1}$
Harima [2002] $K = -3.6\ cm^{-1}/GPa$

I. De Wolf, et al. J. Appl. Phys. 1996, 79 (9), 7148–7156

Stress determined from Raman

✓ Value of Raman frequency higher than the stress-free frequency indicates compressive stress in the sample, while a value of Raman frequency lower than the stress-free one indicates tensile stress.

✓ Tensile stress --- negative value
✓ Compressive stress --- positive value

GaN LED

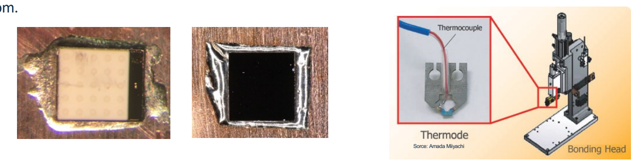
20°C		
Stress [MPa]		
Max	Min	Average
548,39	-716,13	35,18
0,05	0,05	27,37

Si Chip

20°C		
Stress [MPa]		
Max	Min	Average
27,70	-747,34	-470,84
21,66	21,59	21,07

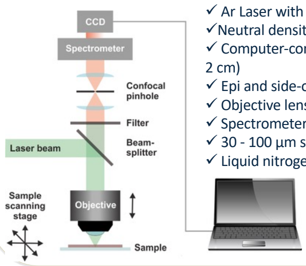
Samples and Assembly Process

✓GaN LEDs, commercially available from the Light Avenue (LA SB47WP6), are vertical GaN thin film on a Si substrate (similar to the Si chip). The chip size was (1000 x 1185) µm with a thickness of 120 µm.
✓Si chips, with dimensions 1500x1500x120 µm3, (001) oriented, and with gold metallization at the bottom.



✓ Samples are bonded to the substrate using soldering technology.
✓Eutectic gold-tin (80/20 Au/Sn) with thermal performance of 57 W/mK is used as a pre-coated layer on the LED bottom and Si wafer side (1 µm thickness) and as preform (25 µm thickness).
✓Soldering is performed in a formic acid vapor atmosphere to prevent oxidation on the surfaces involved in the bonding process.
✓ Samples are assembled on a Cu substrates in different conditions associated to the thickness of the substrate, to the thickness of the bonding layer and to the force (under 0 or 20 N bond pressure), which is applied in the soldering process, under HCOOH atmosphere, at 300 ° C, bonding of 20 s.

Raman Spectroscopy set-up



✓ Ar Laser with wavelengths at 488 nm and 514.5 nm (max. power 600 mW)
✓Neutral density filters for attenuating the laser power in steps
✓ Computer-controlled XYZ sample stage (maximum sample height: approx. 2 cm)
✓ Epi and side-on illumination, and CCD camera for sample observation.
✓ Objective lenses: 4x, 10x, 20x/N.A.=0.75
✓ Spectrometer grating: 1800 mm^{-1}
✓ 30 - 100 µm spectrometer entrance slits range
✓ Liquid nitrogen cooled CCD camera for acquisition of spectra
✓ Raman spectra acquisition parameters:
- 514 nm excitation wavelength
- ~10 mW input power
- 10 s Integration time
- 10 number of acquisitions

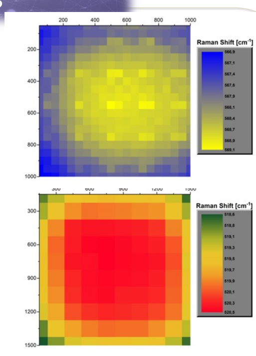
2D Raman Mapping

✓ GaN LED (BLUE-YELLOW graph) shows the larger stress in the central part of the assembled sample
✓ The Raman shift vary from 566,85 cm^{-1} to 569,15 cm^{-1}

20°C		
Peak position [cm^{-1}]		
Max	Min	Averaged Value
569,14	566,85	568,18
0,05	0,05	0,05

✓ Si chip (GREE-RED-YELLOW graph) shows the larger stress in the central part of the assembled sample
✓ The Raman shift vary from 518,63 cm^{-1} to 520,51 cm^{-1}

20°C		
Peak position [cm^{-1}]		
Max	Min	Averaged Value
520,51	518,63	519,85
0,05	0,05	0,05



Conclusions

✓ The determination of the local positions of the stress and the correlation with the soldering process is strategic for the development of increased reliability of the LED-based devices.
✓ Raman spectroscopy is a powerful tool in the characterization of GaN based LEDs. It provides a non-invasive and non-destructive method able to characterize GaN layer of LED soldered with AuSn on Cu substrate. Using Micro-Raman configuration, the Raman mapping of samples provides information of local stresses induced by the soldering process.
✓ The position of the E_2H phonon Raman mode allows to individuate the stress induced on GaN layer by the assembly process, to evaluate its entity, and to correlate it with the experimental conditions. Blue shifts are observed for the optical E_2H mode and explained by the compressive stress: it was possible to map the compressive, tensile and thermal stress of the LED induced by the soldering and compare it with the thermal stress induced on the Si substrate