IOCM 2025 Conference

The 4th International Online Conference on Materials

3–6 November 2025 | Online

MDPI

Raman spectroscopy to evaluate thermomechanical local stress: three case study examples for electronic integrated circuits

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INTRODUCTION & AIM

A crucial point for the realization of devices with high performance, reliability, and durability is the evaluation of the mechanical properties of the materials that constitute the device itself and are necessary for its assembly. Internal stresses can deform the microstructure of the device and occasionally destroy it.

The aim of this work was to investigate the stresses induced in devices during the assembling process as a function of the different assembly parameters, i.e. the physical-chemical characteristics of the involved materials, temperature, and pressure.

The local stress was analyzed in three case studies: the active layer of commercially available GaN-based LEDs and in Silicon and Silicon Nitride chips.
Specifically, great attention was used examining how stress varies depending on bonding processes, such as temperature and pressure of soldering, as well as the impact of bonding and substrate materials on stress evolution. Raman spectroscopy was selected as the primary technique: it is non-destructive and allows for the analysis of materials both before and after bonding.

The Raman investigation was performed on both metal and semiconductor properties of the materials of the integrated circuits. Stress phenomena were determined by 2D Raman mapping of the surface, in a wide temperature range, from -50 to 180° C.

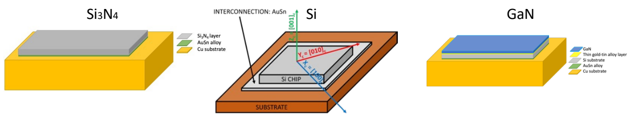
From the determination of the Raman peak position of Silicon, centered around 520 cm^{-1}, Si_3N_4, centered around 865 cm^{-1}, and GaN, centered around 568 cm^{-1}, the presence of tensile and compressive stresses on the samples were evaluated.

The results were correlated to the process parameters to suggest possible optimization procedure to reduce the reliability problems in the structure of optoelectronic devices.

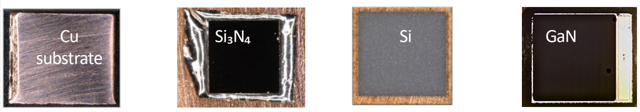
METHOD

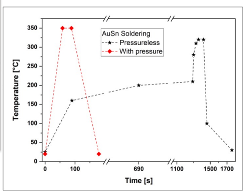
PREPARATION OF SAMPLES

Assembled devices chip on the top, AuSn alloy interconnection and Cu substrate

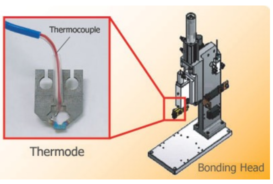


Devices top view

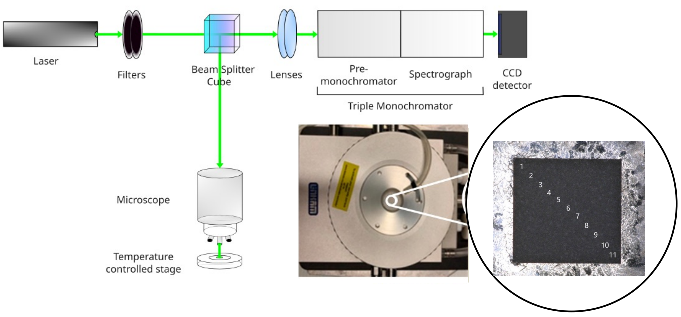




Temperature profile for the soldering process with an AuSn alloy. Without pressure (black stars) and under 5N pressure (red diamond).



RAMAN SET-UP

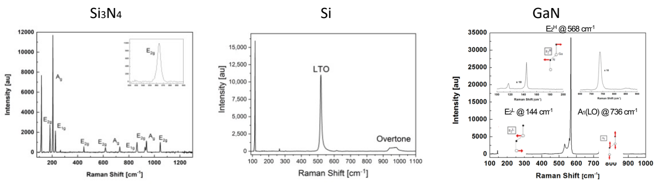


RESULTS & DISCUSSION

RAMAN SPECTRA

The Raman investigation was performed by collecting the Raman peak position of Silicon, centered around 520 cm^{-1}, Si_3N_4, centered around 865 cm^{-1}, and GaN, centered around 568 cm^{-1}

Raman spectra measured using 514.5 nm radiation from an Ar laser.

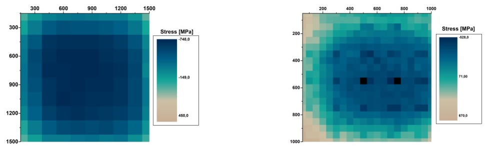


STRESS DETERMINATION

Stress phenomena were determined by Raman mapping of the surface, in a temperature range from -50 to 180°C

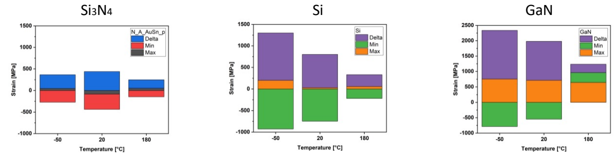
Evaluation of the local stresses induced during the assembling process: linear dependence of the Raman shift to the average value of the total induced "in-plane stress", through the biaxial stress coefficient: $\Delta\omega(E_2^H) = -1.55 \cdot 10^{-9}(\sigma_{xx} + \sigma_{yy})$, where $(\sigma_{xx} + \sigma_{yy})$ is the average value of the total induced "*in-plane strain*"

Stress maps of Si (left) and GaN (right) at 20°C.



All samples present a stress distribution with a symmetric profile with respect to the central area of the chip.

Maximum and minimum strains developed on samples as a function of the temperature



High compressive stress values are common for all gold-tin interconnected samples using 1.5 mm thick copper substrate
The Si_3N_4 sample exhibits significant differences in stress values compared to the Si and GaN assemblies. At low and room temperatures, the difference in maximum stress values between the assemblies is approximately 400 MPa, reducing to around 90 MPa at 180°C. The strong reduction in the stress difference at 180°C suggests that the thermal expansion behavior and the mechanical properties of the materials are temperature-dependent. At higher temperatures, the materials may undergo more significant relaxation and plastic deformation, leading to a more uniform stress distribution.

CONCLUSION

One of the most challenging problems in the device assembly processes is the development of thermomechanical stress, which is considered mainly due to the mismatch of the thermal expansion coefficient of the different components. Temperature and mechanical stress are important variables, that must be monitored during the entire production process, firstly, and working phase, secondly. Indeed, local deviations can lead to uncontrolled changes. The possibility of using micro-Raman for process control is beneficial for optimizing assembly processes.

FUTURE WORK / REFERENCES

Raman measurements allow clearly the identification and quantification of stress on samples assembled with AuSn solder. This problem must be considered to improve the mechanical reliability of the bonded joints.

Studies on sintering are ongoing as an alternative to soldering.