Application Note
Semiconductor
UVISEL
Spectroscopic Ellipsometry
SE13

Characterisation of III-V Semiconductors using Phase Modulated Spectroscopic Ellipsometry: InGaAs Avalanche Photodiodes

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III-V semiconductors materials allow the manufacture of high performance optoelectronics and hyperfrequency devices.

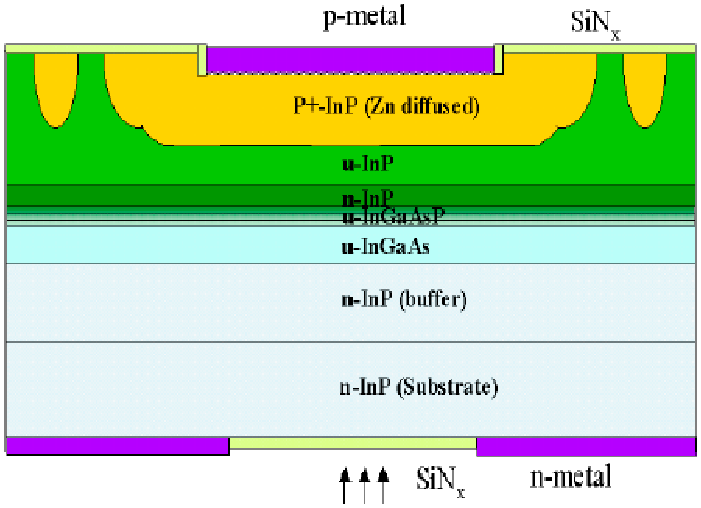
One such device is the Avalanche Photodiodes (APD), and this is a promising solution to the increasing demand for high-performance optical transmission systems to detect low optical signals in applications such as long-distance fibre communications, spectrometry and laser radars. However, several problems remain to be resolved for their use as high-speed optical detectors. The problems include low reliability and narrow structural margins for very high-speed responses.

Many researches have focused on improving their performance via techniques such as band gap engineering and optimization of device structures in III-V compound semiconductors. These structures have offered large gain-bandwidth products and high performances at 1.3 and 1.55 μm wavelengths. To reach the desired performance multilayer alloy structures must be grown with accurate thickness and composition using epitaxial reactors such as MBE, MOVPE or MOCVD, and accurately characterised using a non-destructive test method.

The UVISEL NIR Spectroscopic Ellipsometer provides a fast, non destructive characterisation tool which has helped to improve the manufacturing yield of APDs. The accuracy and reliability of the ellipsometric measurement has allowed replacement of the selective chemical etch used to measure the thicknesses. The UVISEL Spectroscopic Ellipsometer may also be applied to the characterisation of laser structures, photodetectors and many other complex multilayer devices.

How does an APD work?

An avalanche photodiode is essentially a PIN or PN photodiode operating at high reverse bias. At such a high bias the free carriers (electrons and holes) in the depletion region are accelerated to high speeds. Such a carrier with high kinetic energy can excite an electron in the valence band to the conduction band and therefore create an electron and a hole. This one-carrier ⇛ three-carrier process is called an impact ionization or avalanche process. As a result, the current is amplified.

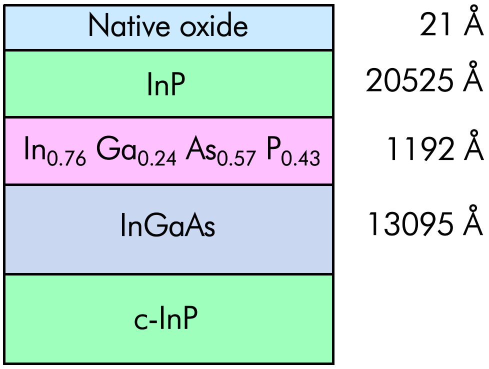


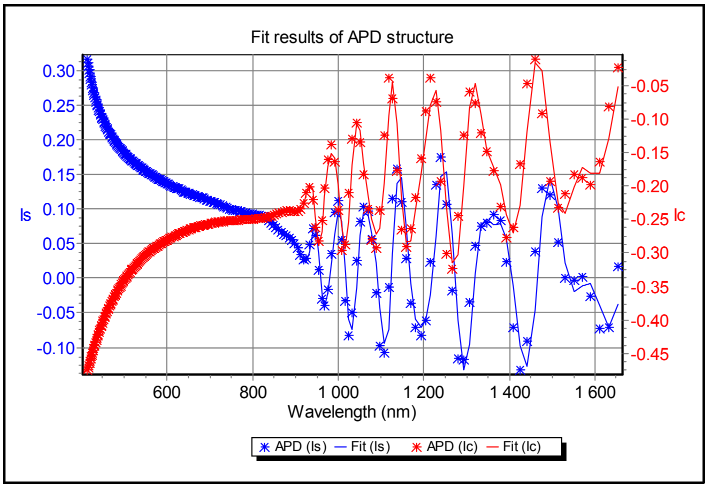
InGaAs APD Photodetector Epitaxial Structure

APD structure characterisation

Spectroscopic Ellipsometry (SE) allows the non-destructive characterisation of APD structures with high accuracy and precision. The ellipsometric data were collected at an angle of 70° using the Jobin Yvon UVISEL NIR (260-1700 nm). In the APD structure the materials involved are absorbing in the visible region and become transparent in the NIR. As a consequence this is the optimal range for the present study.

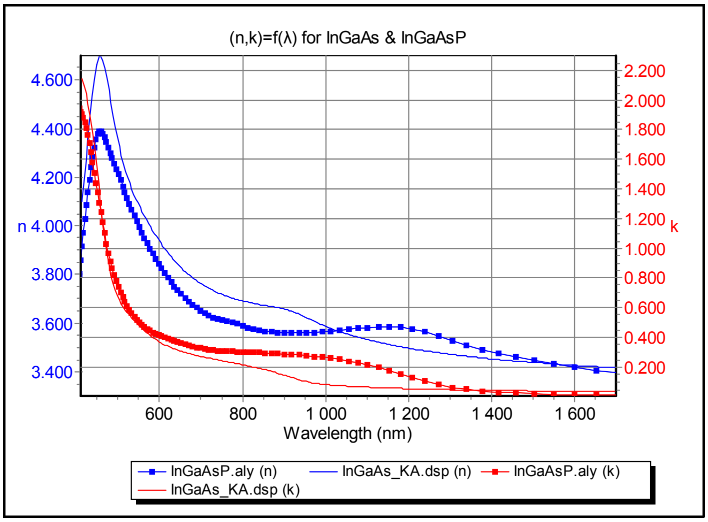
Both refractive indexes and thicknesses of each material were extracted simultaneously from the SE data analysis in the range 410-1700nm.
The structure includes a native oxide layer at the top of the structure which improves the goodness of fit (χ^2) parameter. This native oxide is described by a 50/50 mixture of material + void based on the Effective Medium Approximation (EMA).





Determination of optical constants

The optical constants for InGaAs were calculated using the «Kato-Adachi» dispersion formula, Adachi formula reduced (Jpn. J. Apl. Phys. Vol. 33 (1994) pp.186-192). The fit consist to fit the eleven parameters of this formula. Each term of the equation represents an electronic transition, and allows calculation of the material band gap through the E_0 term.
For the InGaAsP quaternary alloy the complex index was calculated using the "Alloy Material" function of DeltaPsi2 software. In addition to calculating the optical constants, extra information is provided by the software to identify which alloy compositions present in the structure.



Conclusion

The high accuracy characterisation of the thicknesses and optical properties of III-V semiconductors has been successfully performed using the UVISEL Spectroscopic Phase Modulated Ellipsometer. Moreover, Spectroscopic Ellipsometry can be applied to characterise multilayers of miscellaneous binary, ternary semiconductors and alloys (MQW structure, PIN structure, pump laser, laser semiconductor,...).