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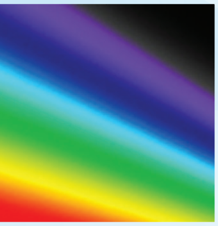
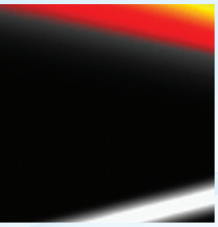
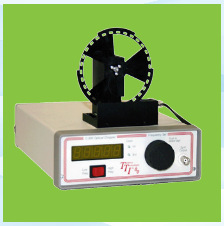


Photoluminescence and Photoreflectance

OSD-PL-01

ELEMENTAL ANALYSIS
FLUORESCENCE
GRATINGS & OEM SPECTROMETERS
OPTICAL COMPONENTS
FORENSICS
PARTICLE CHARACTERIZATION
RAMAN
SPECTROSCOPIC ELLIPSOMETRY
SPR IMAGING





Optical Characterization of Semiconductor Devices

Introduction

As a result of rapid development in semiconductor manufacturing, many types of optoelectronic devices such as laser diodes, LEDs, and high-electron-mobility transistors (HEMTs) are now fabricated by epitaxial-growth methods. To improve and characterize their quality, these devices are optically inspected. Photoluminescence (PL) and photoreflectance (PR) spectroscopy are among the most important optical methods. PL and PR are contactless, non-destructive techniques, and different kinds of optical information can be acquired from each. PL studies photons emitted from a material or device when excited by an external light source. PL emissions may result from radiative recombination mechanisms such as direct bandgap, intersubband energies, excitonic states, defect states, and impurity level mechanisms. PL is more powerful for studying the luminescence properties of materials near and below the fundamental edge.

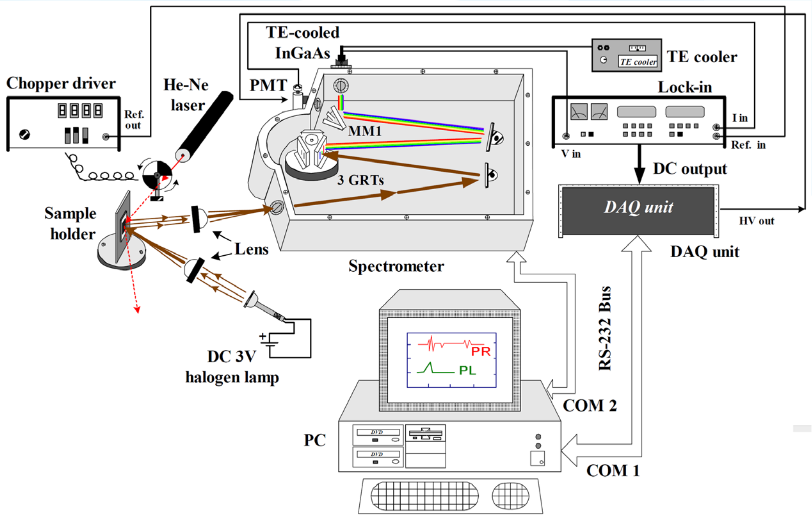


Figure 1: Experimental setup of system used for measuring PL and PR of semiconductors.

To characterize interband transitions above the band edge, modulation spectroscopy methods such as PR are useful. In a PR experiment the electric field is modulated in a sample via creation of electron-hole pairs by a pump source (laser or other light source) chopped at a given frequency. Periodic photoperturbation of the sample causes a derivative-like spectral feature at the critical-point transition of the reflectance spectrum. The derivative-like nature suppresses background effects and emphasizes structures localized in the energy region near direct interband transitions of semiconductors.

Experiment

The experimental setup is shown in Fig. 1. An iHR320 (or TRIAX320) imaging spectrometer with three gratings on a computer-controlled turret (600, 1200, and 2400 gr/mm) optically dispersed the emssion. Two detectors were mounted on the exit ports: a photomultiplier tube for visible emissions, and a thermoelectrically cooled InGaAs photodiode for near-IR emissions. The overall spectral measurement range was 190 to 1650 nm. An optical chopper modulated the laser beam for both PL and PR measurements, with a lock-in amplifier for synchronous detection. For PL measurements of the HEMT device, a frequency-doubled Nd:YAG laser (532 nm) with average output power of 100 mW was the pump source. For PR measurements, a DC 3 V tungsten-halogen lamp was the white-light source, and a He-Ne laser (632.8 nm) acted as the modulation light source of the HEMT sample.

Measurements of an InGaAs/GaAs graded-channel HEMT have been carried out with this PL and PR system.

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Results

The performance of the PL-PR system was tested with two selected samples of a graded-channel $In_xGa_{1-x}As$/GaAs HEMT device. The sample was grown on a computer-controlled LP-MOCVD.

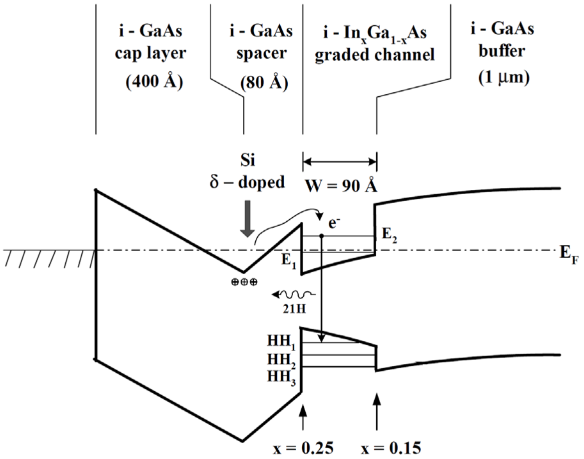

Figure 2: Representative energy band diagram of a selective sample of $In_xGa_{1-x}As$/GaAs graded-channel HEMT.

Fig. 2 shows the representative energy-band scheme of the graded-channel HEMT. A 2DEG was formed in the channel layer as a result of the electrons' spilling over the band discontinuity from the N + δ doped GaAs layer into the $In_xGa_{1-x}As$/GaAs grading channel, which also shifted the Fermi level above the conduction-band edge inside the channel well.

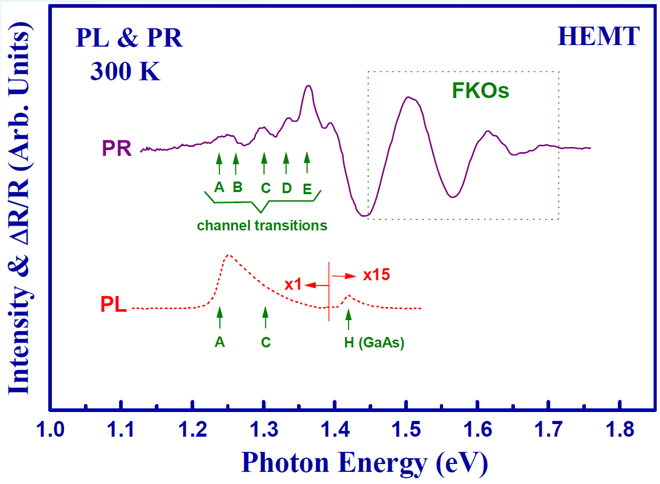

Figure 3: Experimental PR and PL spectra of the $In_xGa_{1-x}As$/GaAs graded-channel HEMT device.

Fig. 3 shows the experimental PR (solid curve) and PL (dashed curve) spectra of the graded-channel HEMT. There are many transition features (denoted A, B, C, D and E) as well as a prominent spectral oscillation observed in the PR spectrum. The transition features are closely related to the well intersubband transitions of the grading-channel layer. The Franz-Keldysh oscillations (FKOs) at the higher-energy side are often used to determine the built-in electric field inside the semiconductor device.

Experimental results are summarized in Table 1.

Table 1. Experimental values of the intersubband transition energies from the $In_xGa_{1-x}As$/GaAs graded-channel layer of an HEMT structure with 2D sheet density N_s obtained by PR measurement

Feature	Inter-subband transition	Transition energy		$E_F - E_1^c$ (meV)	2DEG (N_s) (cm^{-2})
		PR	PL		
A	11H	1.238 ± 0.005	1.238	6 ± 2	$(6.5 \pm 0.5) \times 10^{11}$
B	12H	1.264 ± 0.005			
C	21H	1.300 ± 0.005	1.301		
D	22H	1.329 ± 0.005			
E	23H	1.360 ± 0.005			
H (GaAs)			1.421		

Conclusions

The HORIBA Scientific system described in this paper was used for photoluminescence (PL) and photoreflectance (PR) measurements on semiconductor devices. From analyses of the PR and PL spectra of the graded-channel $In_xGa_{1-x}As$/GaAs HEMT device, the intersubband energies, Fermi-level location and 2D sheet density of the graded $In_xGa_{1-x}As$ channel were determined.

References and Acknowledgements

This material was used with permission from Prof. Ching-Hwa Ho, Department of Materials Science and Engineering, National Dong Hwa University, Taiwan. [C.-H. Ho, *et al.*, *Opt. Express*, **13**, 3951–3960 (2005).]

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