Strain Detection in III-V Semiconductors Using Polarization Resolved Photoluminescence

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Mechanical strain, *i.e.*, a deformation of the crystal lattice caused by an external stress, can affect the reliability and performance of III-V semiconductor devices. The refractive index is a function of strain and, thus, so are the optical guiding properties of devices. Diode lasers, LEDs, and transistors are thought to degrade more rapidly if processing induced stresses exceed a threshold level.[1]

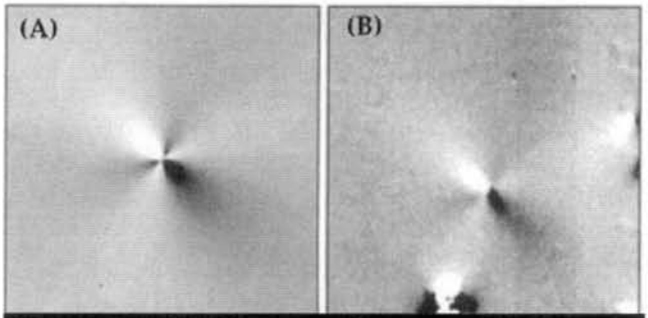
Traditionally, strain in semiconductors is measured using techniques that are destructive or that lack the spatial resolution and/or strain resolution to detect the strain fields around the micrometer-sized features of devices.[2,3]

In luminescent III-V material, strain that reduces the symmetry of the crystal lattice can be detected by analyzing the degree of polarization of spontaneously emitted light.[4] The rate of emission of light polarized parallel to the direction of a strain is greater than the rate of emission of light polarized perpendicular to the direction of a strain for a compressive, uniaxial strain. By comparing rates of emission of light along two orthogonal directions, strains as small as 3×10^{-6} can be measured. The difference in the rate of emission can be measured accurately with a polarizing beamsplitter cube, two optical detectors, and two lock-in amplifiers.

The light to be analyzed can be created by photoluminescence (PL). With PL, maps of the strain field over a surface of a semiconductor can be obtained with a spatial resolution of 1 µm. The PL technique has been used to measure stress distributions in InGaAsP and AlGaAs diode lasers and LEDs. Strain fields caused by metallization layers, dielectric layers, ridge structures, and soldering to heatsinks have been obtained.[5]

Polarization-resolved PL is capable of detecting the strain field around individual dislocations in III-V semiconductors.[6] The Burgers vector and type of the dislocation can be obtained from an analysis of the strain pattern. Dislocations play an important role in the yield of reliable devices. Therefore, techniques to detect and to characterize dislocations are required. Polarization-resolved PL offers a simple, relatively inexpensive, non-destructive technique for detecting and characterizing dislocations, including misfit dislocations in strained epitaxial layers. The nondestructive nature of the technique is significant since it enables screening of substrate materials and epitaxial layers before processing.

Part (a) of the figure is a theoretical plot of the strain field about an edge dislocation that has penetrated the free surface of an InP sample. Part (b) is an observed strain field on an InP sample over a 50×50 µm^2 square area. The data was obtained using polarization resolved PL. Note that the strain field is observable for a diameter of 30 µm about the dislocation core. For this dislocation, the PL signal was suppressed by 10% for a diameter of one µm about the dislocation core.



(A) Calculated strain field over a 50×50 µm^2 area for an edge dislocation intersecting an InP surface at normal incidence and with a Burgers vector of 0.415 nm directed from the top left corner to the bottom right corner of the figure. (B) Experimentally observed strain field on the surface of InP using polarization resolved PL. Note the similarity with (A).

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Laser Diode Delivers Atomically-Resolved Images

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Optical microscopy has a diffraction-limited resolution determined by the wavelength of the laser and the numerical apertures of the objective and condenser. Even for the best optical microscope, this resolution is limited to several hundreds of nanometers. It has recently become possible to circumvent diffraction limitations and increase the resolu-