Enlightenment - Cathodoluminescence: The Bright Technique, Part I

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This is the first in a series of articles that serve to identify what scanning Cathodoluminescence can offer the materials technologist. Whilst begining with Electronic Materials, Geological, Ceramic and Diamond applications will be covered over the next installments concluding with a reveiw of instrumentation needed to perform the studies covered in the final chapter.

Cathodoluminescence (CL) is the most important optical phenomenon used by all electron microscopists. It is the process by which electrons are converted into light in the Everhart Thornley secondary electron detector and also in the screens and cameras of TEMs.

Cathodoluminescence, however, can be used as an analysis technique in its own right to study materials which exhibit this phenomenon[1]. Amongst these are semiconductors of all types used for devices, optoelectronics and light emitting materials, geological materials, ceramics and diamond materials.

Cathodoluminescence arises as a result of electrons being excited into the conduction band of these materials, and subsequently recombining with holes left in the valence band. The energy difference is equalised by the emission of a photon. Depending on the process of recombination the photons will have the energy of the bandgap in the case of direct transitions or less than that in the case of indirect transitions.

Semiconductors

It is possible within this important class of materials to observe many of the defects that plague their successful manufacture. Gallium arsenide layers on silicon for use in integrated optoelectronic circuits are prone to cracking because of strain set up by the lattice mismatch between the silicon substrate and the GaAs epilayer (lattice mismatch @ 4%). These cracks can hardly be seen in a secondary electron image as illustrated in Figure 1. However the reduction in strain which occurs near the edges and along the cracks alters the wavelength of CL emission as indicated in the spectra in Figure 2 which were from the points (a) and (b) in Figure 1.

This area of strain relaxation can be visualised by setting the monochromator to the wavelength that corresponds to the unstrained material. Figure 3 shows the unstrained regions which are emitting at 800nm which corresponds to an energy transition of 1.549 eV[2].

Other popular uses of CL are for the studies of quantum confined structures (wells, wires & dots) which are being developed for diode laser structures. Here CL can assist in observing the uniformity of the emission at different wavelengths as shown in the examples as follows.

Here InGaAs quantum wells have been grown onto v-grooves on semi-insulating InP. CL spectroscopy at room temperature indicated the presence of two major peaks as shown in Figure 4.

Setting the monochromator to these two emission wavelengths allows a pair of complimentary images to be taken which indicate not only the spatial distribution of the emission centres but also areas where the emission is degraded because of defects in the structures. Many of these effects are not visible by any other imaging technique and certainly not with the high spatial resolution obtained with CL.

One of the most vibrant areas of opto electronics research at present is in the production materials that emit in the UV and blue regions of the electromagnetic spectrum.

Blue LED's and laser diodes have applications as diverse as diode based traffic signals with enormous power savings to using blue light to write increased volumes of data onto optical discs as a result of the shorter wavelength.

One of the many wide band gap materials that has been proposed for this purpose is gallium nitride.

Recent research by CL into gallium nitride based materials for blue LED's has allowed the sites for different emissions to be resolved. Previous photoluminescence (PL) studies have been incapable of providing this spatial information although have provided excellent spectral information as displayed in the upper two spectra of Fig 7. CL has provided the spectral information in the lower spectrum and by imaging both the blue (364 nm) and yellow (559 nm) emissions it has been possible to observe the different sites responsible for these effects which are shown in Figures 9 and 10.

Interestingly the light emission from the band edge and yellow regions in these undoped materials is inhomogeneous. The intensity of the band edge and yellow emissions correlate with columnar grain sizes obtained by TEM. It is hypothesised that the sources of the yellow emission are either dislocations at low angle grain boundaries in the material or point defects which nucleate at the dislocations[3].

Dislocations due to lattice mismatch can also be observed in epilayers of other materials. In Fig 10 a network of misfit dislocations are observed in a GaAsP epilayer on a GaP substrate at room temperature. These would be impossible to observe by other imaging techniques.

Acknowledgements

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1 Yacobi, B.G., Cathodoluminescence Microscopy of Inorganic Solids, Plenum Press ISBN 0-306-43314-1.

2 Norman, C. and Murray, R, Microscopy of Semiconducting Materials, Oxford 1993.

3 Ponce, F.A. et al, Applied Physics Letters in press.

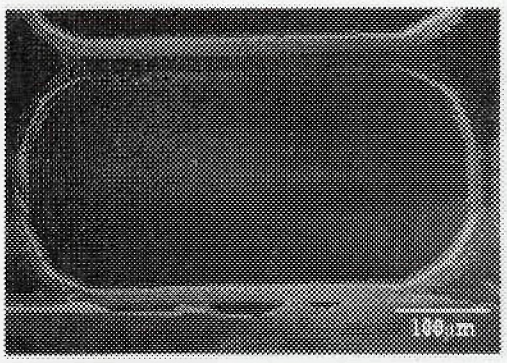


Figure 1: Secondary electron image of gallium arsenide layer on a patterned silicon substrate.

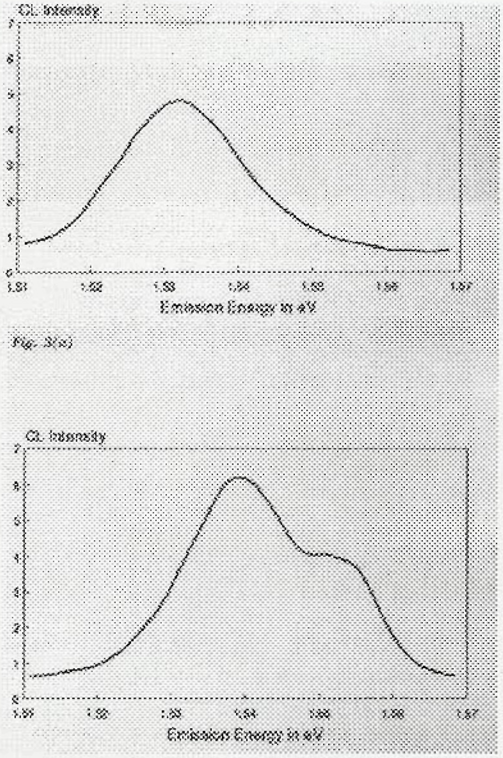


Figure 2: CL Spectra from points a & b in Figure 1.

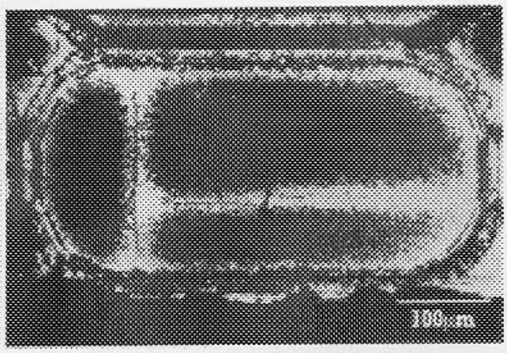


Figure 3: Monochromatic CL Image at 800 nm which corresponds to the area of reduced strain due to edge effects and microcracks.

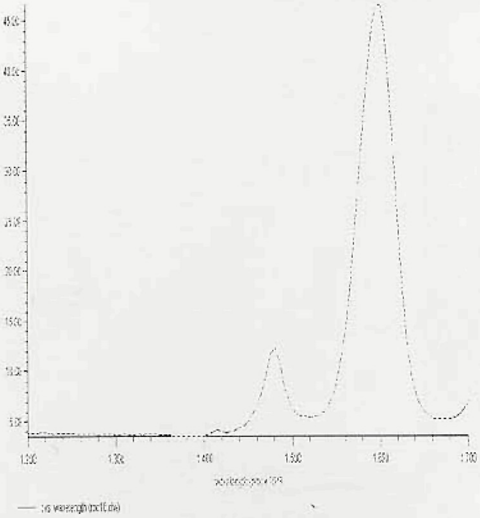


Figure 4: CL Spectra of InGaAs quantum well on InP v-groove substrate.

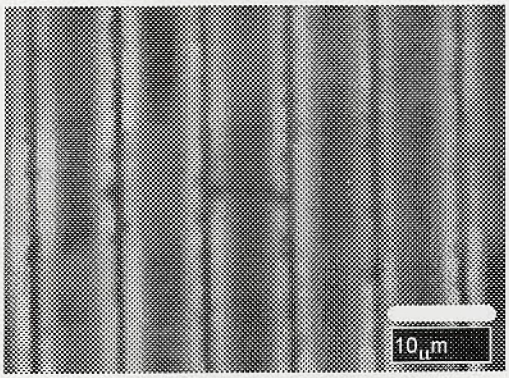


Figure 5: CL image at 1422 nm of InGaAs quantum well on InP v-groove substrate.

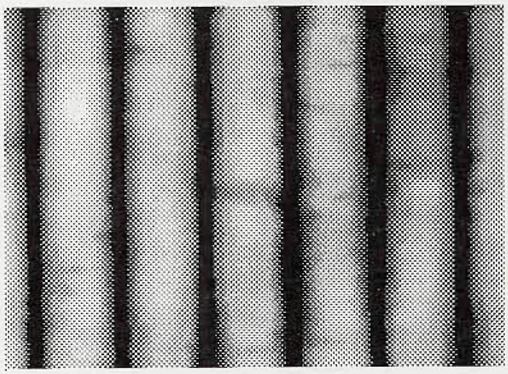


Figure 6: CL image at 1577 nm of InGaAs quantum well on InP v-groove substrate.

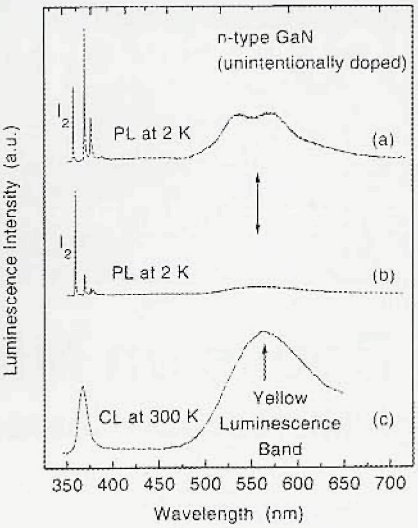


Figure 7: Luminescence spectra of non-intentionally doped GaN thin films.

(a) with uniform surface morphology

(b) with a surface dominated by hexagonal crystallites

(c) CL at room temperature.

Figure 8: Secondary electron image of undoped GaN film showing the morphology.

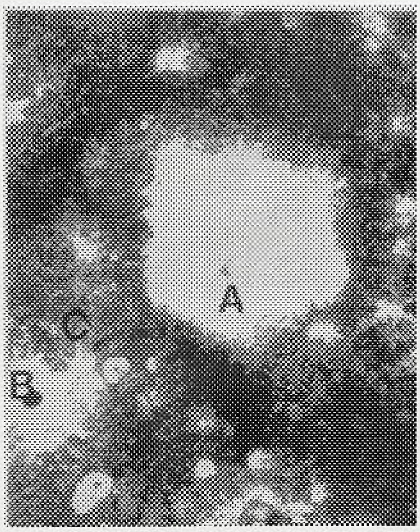


Figure 9: Monochromatic CL image at 364 nm showing that the band-to-band emissions are distributed only in the crystallites.

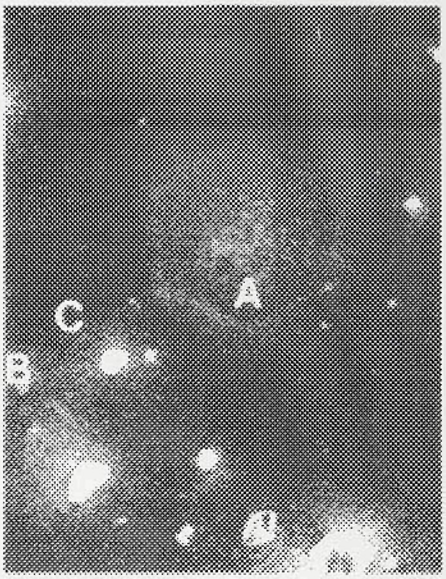


Figure 10: Monochromatic CL image at 559 nm showing that the yellow emissions are distributed in the crystallites and in the boundaries.

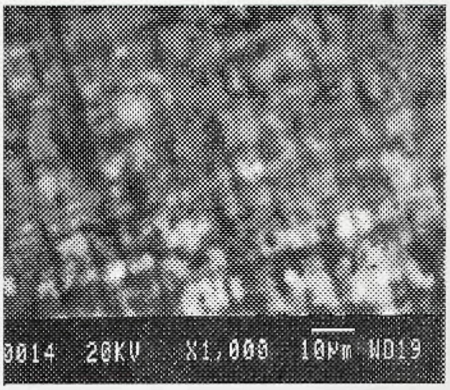
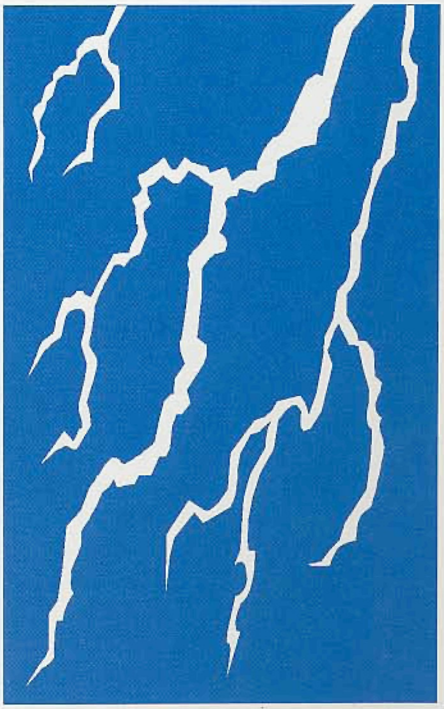


Figure 11: CL Image of a network of misfit dislocations in a GaAsP epilayer on a GaP substrate at room temperature.



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