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A-4-3 Optical Compensation Profiling in Direct-Gap Epitaxial Layers

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The compensation, i.e. the ratio between minority and majority dopant concentrations, is a significant parameter of semiconductor materials and can be of vital importance for recombination or lifetime controlled devices, such as semiconductor lasers, FET's, or Gunn devices.
We actually present examples of profiles of the compensation as a function of depth in gallium arsenide epitaxial layers. The profiles were obtained with an optical method recently developed for direct-gap semiconductors. We exploit the spatial resolution of this method, which is inherently much higher than that achieved with purely electrical means. Our experiments show that the usual doping profiling does not conclusively describe the compensation profile and hence does not sufficiently characterize epitaxial layers for high performance devices.

Our method of determining the compensation is based on the analysis of optical transitions at low temperatures. By means of photoexcitation, the radiative transitions from both the conduction band and the donor level to the acceptor states (i.e. the (e,A^o) and the (D^o,A^o) transitions) are investigated. The lineshapes and the intensity ratio of these transitions can be described in terms of the temperature, the acceptor, donor, and Fermi energies, the majority dopant concentration, the band parameters, and the transition rate of competing processes. While most of these quantities are well-defined material constants, the Fermi level and the rate of competitive transitions are used as fitting parameters to the experimentally measured lineshapes. The net carrier concentration n , needed as an additional quantity for the calculation of the compensation, can easily be obtained from conventional capacitance-voltage measurements with high accuracy.
The gallium arsenide layers investigated were LPE-grown and have carrier concentrations between 5×10^{13} and 2×10^{15} cm^{-3} at room temperature. The analysis of their compensation profiles is made possible either by angle lapping or by stepwise etching of the epitaxial layers. The luminescence spectra were recorded under well-controlled low-excitation conditions with the use of an argon laser and single-photon counting technique.
A correct fit of the spectra throughout the temperature decade between 1.8 K and 15 K provides a stringent test for the accuracy of the compensation values

The spatial resolution of this method is in principle limited by three factors: 1) the absorption length of the excitation light, 2) the diffusion length of the charge carriers, and 3) the diameter of the illuminated spot for the case of angle lapping. The laser beam was focussed to a 100 µm - diameter spot, giving no limitation in resolution at the lapping angles used of 10' through 30'. The laser light (λ = 514 nm) is absorbed within distances as small as 0.15 µm, whereas the diffusion length has values of 1 through 5 µm - depending on the gross dopant concentration and the compensation. Therefore the depth resolution is limited by the diffusion length of carriers. It is appreciably higher than the resolution obtainable with the purely electrical method based on Hall mobility measurements.

The analysis of luminescence spectra is performed for one acceptor state only (e.g. for the shallow acceptors carbon or silicon in GaAs); the technique nevertheless provides the value of compensation including all acceptor states, because the position of the Fermi level is determined by the levels and concentrations of all the dopants in the material.

The experimental results show that compensation profiling provides important insight to the composition of epitaxial layers, and can furnish information for the layer growth procedures and, when combined with device preparation, technology control.