CHARACTERIZATION OF DEFECTS IN SEMICONDUCTORS BY CAPACITANCE METHODS

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The presence of lattice defects in semiconductors may be shown easily by electrical and optical methods. The most powerful and direct methods for identification of various kinds of defects are electron-spin-resonance (ESR) and infrared absorption combined with the uniaxial stress. Unfortunately, those methods have been applied successfully only to a restricted number of semiconductors. (For instance, they work well in the case of silicon.) All other experimental methods may reveal some physical properties of defects, being unable to make a direct identification. Some of the most important data are: energy level positions in the gap, defect concentrations, and thermal and optical capture and emission coefficients of minority and majority carrier traps. The additional useful characteristics are: donor or acceptor behaviour, spatial homogeneity of defects, annealing temperature and eventual dependence of capture or emission coefficients on the electric field or temperature. None of the methods alone can provide all those data.

Beside shallow donors or acceptors, there is a special class of defects, introduced unintentionally during synthesis or fabrication of semiconductor devices which have quite often a very profound influence upon their properties. Those are traps for majority and/or minority carriers with energy levels located deeper in the gap.

Whereas the shallow localized energy levels may be characterized very well by photoluminiscence or optical absorption measurements, or, to a somewhat lesser degree of precision, by Hall-effect and conductivity measurements, those methods are much less efficient in the case of deeper center, and especially, if they are nonradiative. For majority of such centers, the basic parameters such as thermal capture and emission coefficients have remained completely unknown.

However, in recent years several experimental methods were developed, based on capacitance measurements of potential barriers in semiconductors, which may circumvent those difficulties and provide the necessary data. The majority of these methods works equally well with p-n and Schottky junctions, insuring their general application.

Here we point out and discuss the main features of some of the most important capacitance methods:

a) capacitance of the Schottky-barrier as a function of applied voltage and frequency (1), b) admittance spectroscopy (2), c) thermally stimulated capacitance (TSCAP) (3), d) edge region TSCAP (4), e) photocapacitance (5), and f) deep-level transient spectroscopy (DLTS) (6).

The first method is applicable only to the majority carrier traps. It provides their energy levels, concentration of traps, thermal capture coefficients, degeneracy factor, and the true value of the diffusion or built-in potential. The method is slow and not spectroscopic in nature. It is very good for detection of very shallow traps.

The second method consists of admittance measurements as a function of temperature, at two frequencies at least. It is a spectroscopic method independent of thermal scan rate or direction. However, it is also limited to majority-carrier traps. It is at its best for shallow traps with decreasing sensitivity for the deeper traps, providing level energies, capture coefficients, concentrations and types of defects (donor or acceptor).

The TSCAP method is spectroscopic, but limited to traps deeper than approximately 0.25 eV. It can detect their presence down to 10^{14} cm^{-3} in concentration. For shallower traps, it requires measurements below 77 K.

Edge region TSCAP can observe very shallow and intermediate majority-carrier traps in the junction edge region at temperatures higher than 77 K, but it is less sensitive than the ordinary TSCAP method. Both methods provide energy levels, their concentrations, the first being able to distinguish between the majority and minority carrier traps.

Photocapacitance may detect traps in concentrations as low as 10^{12} cm^{-3}, but it is slow and limited to traps deeper than about 0.3 eV. It is less useful as a survey method, but it is very valuable in precise investigations of optical properties of a specific deep trap.

The last method DLTS is a fast spectroscopic method for all kinds of traps (especially for fast nonradiative ones). It detects traps down to 10^{12} cm^{-3} in concentration, and provides their energy levels, concentration profile, electron and hole capture and emission coefficients, and may reveal temperature or electric field dependence of those coefficients. It cannot see the shallow centers such as donors and acceptors, or bound excitons. This is actually a high frequency capacitance transient thermal scanning method where a dual-gated signal integrator provides a variable selected rate window for a detection of particular traps. In comparison to thermally stimulated current methods, DLTS has a better immunity to noise and surface channel leakage current, and may distinguish between majority- and minority carrier traps.

The general feature of all capacitance methods is that they can detect traps in very low concentrations, several orders of magnitude lower than the concentration of the dominant doping impurities, which give rise to shallow donor or acceptor levels.

References

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