

B-3-7

Isothermal Capacitance Transient Spectroscopy

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Introduction Extensive study of the nature of deep levels in semiconductors has been required in device processes. For example, detailed knowledges of Au in Si are needed to control the minority-carrier lifetime in Si pn junction devices or those of deep levels in laser-diode materials such as $\text{Ga}_{1-x}\text{Al}_x\text{As}$ are also needed to preserve from the degradation. The TSC (Thermal Stimulated Current) method¹⁾ or the DLTS (Deep Level Transient Spectroscopy) method²⁾ has been used as a spectroscopic tool for deep level analysis. However, it is difficult to measure the accurate temperature of the specimen in these spectroscopic methods, because the temperature of the specimen is continuously increased or decreased in these methods. Furthermore, it is not easy to construct a precise measurement and analysis system by a programmable calculator in these methods because digitizing and memorizing of the analog signals accurately are difficult under the continuous thermal scan. In this report, a new measurement method for deep levels in semiconductors (ICTS, Isothermal Capacitance Transient Spectroscopy) is proposed, by which the measurement of the transient change of capacitance is performed under an isothermal condition. The method allows us to construct a precise measurement and analysis system by a programmable calculator and it will become one of useful tools for spectroscopic analysis of deep levels in semiconductors.

Principle of the method The ICTS method presented here is a variation of capacitance transient spectroscopy. If $C(t)$ and C_0 are the capacitance of the depletion region of p^+n junction at time t and ∞ after applying an injection pulse or a majority-carrier pulse, respectively, we find the following relation³⁾,

$$f(t) \equiv C^2(t) - C_0^2 = \sum_i B^i \exp(-t/\tau^i), \quad (1)$$

where $B^i = qk_s \epsilon_0 A^2 \Delta N_I^i(0) / 2(V_D + V_R)$, $\tau^i = (e_n^i + e_p^i)^{-1}$, q the electronic charge, $k_s \epsilon_0$ the dielectric constant, A the junction area, $\Delta N_I^i(0)$ the increment of the concentration of filled i th deep level at $t=0$, V_D the built-in potential, V_R the DC reverse bias voltage and e_n^i (e_p^i) the emission rate for electrons (holes) at i th deep level. It is noted that $\Delta N_I^i(0)$ is a function of e_n^i and e_p^i . Differentiating eq.(1) and multiplying the result by t , we obtain,

$$t \frac{df(t)}{dt} = \sum_i B^i (-t/\tau^i) \exp(-t/\tau^i). \quad (2)$$

This equation indicates that $t df(t)/dt$ has a maximum value of $-B^i/e$ near $t=\tau^i$. Therefore, if we obtain the function $t df(t)/dt$ from the transient capacitance measurement under an isothermal condition, the deep level parameters B^i and τ^i are given spectroscopically from the relation between $t df(t)/dt$ and t . B^i and τ^i are functions of e_n^i and e_p^i . Therefore, e_n^i and e_p^i are determined uniquely from the values of B^i and τ^i . The concentration of i th deep level can be obtained from B^i . The deep level depth can be calculated by measuring τ^i at several temperatures.

In an actual measurement, we measure the transient change of capacitance $C(t)$ after applying

an injection pulse or a majority-carrier pulse under an isothermal condition. Signals of $C(t)$ are converted to digital signals and memorized in a computer system and the relation between $tdf(t)/dt$ and t is obtained by numerical calculation. Detailed analyses of B^i and τ^i are also performed in the same computer system.

Simulation of ICTS It is very instructive to make a simulation of the ICTS method in the case of Au-doped Si and to compare with that of the DLTS method. The model used in the simulation is the same as that used successfully in the simulation of the DLTS on Au-doped Si p⁺n diodes⁴⁾. Figure 1 shows both the ICTS and the DLTS signals under the minority-carrier pulse application. In these cases, two peaks appear corresponding to the Au donor and acceptor levels. The simulation results show that the information obtained from the ICTS signal is equivalent to that from the DLTS signal.

Experiment Figure 2 shows a block diagram of our ICTS system. The fast capacitance meter and the transient converter can follow the variation of signal to about 1 μ sec. An HP 9825A calculator and an HP 7245A plotter/printer are used. The specimen used in the experiment was fabricated from Au-diffused Si p⁺n junction wafers whose N_D was $2 \times 10^{15} \text{ cm}^{-3}$. Figure 3 shows a typical ICTS signal obtained experimentally under the majority-carrier pulse application. This result is in good agreement with that of the simulation. The Au concentration and energy level depths determined by the ICTS agree fairly well with those by the DLTS.

Concluding remarks The basic idea of the ICTS is presented and its computer simulation and experiment are demonstrated. We consider that the ICTS method will become one of useful tools for spectroscopic analysis of deep levels in semiconductors.

REFERENCES 1) Topics in Applied Physics ed P. Bräunlich (Springer-Verlag, New York, 1979) Vol. 37. 2) D.V. Lang: J. Appl. Phys. 45 (1974) 3023. 3) C.T. Sah et al: Solid-State Electron. 13 (1970) 759. 4) H. Okushi and Y. Tokumaru: Technical Group Meeting on Solid-State Devices, IECE, Japan, SSD 78-100.

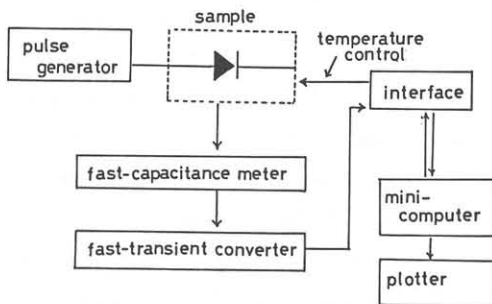


Fig. 2. A block diagram of the ICTS system used in the present work.

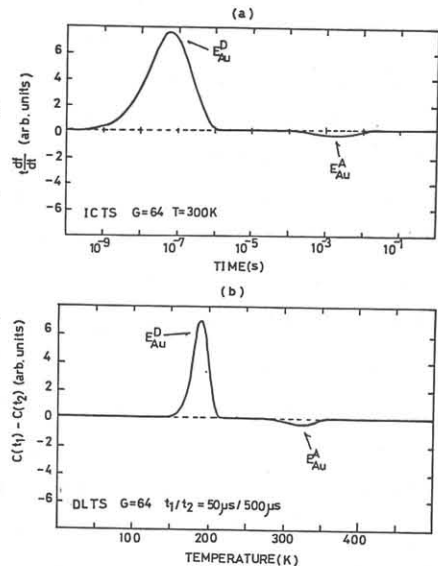


Fig. 1. Computer simulation; (a) ICTS signal for a Au-doped Si p⁺n diode under the minority-carrier pulse application at $T=300\text{K}$. (b) DLTS signal corresponding to (a) at the rate window $t_1/t_2=50\mu\text{s}/500\mu\text{s}$.

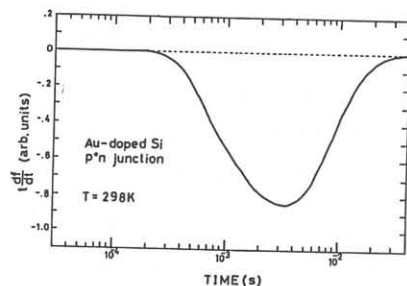


Fig. 3. ICTS signal obtained experimentally for a Au-doped Si p⁺n diode under the majority-carrier pulse application.