

Injection Level Spectroscopy: A Novel Non-Contact Contamination Analysis Technique in Silicon

George FERENCZI, Tibor PAVELKA, Péter TÜTTŐ

SEMILAB Semiconductor Physics Laboratory Rt

H-1047 Budapest, Fóti út 56. Hungary

Microwave photoconductivity decay was measured in the function of the excitation light intensity. Using a new approach to analyze recombination lifetime data an experimental method is presented which is capable of producing qualitative lateral deistribution maps of different metal contaminants in a silicon wafer.

The presence of transitional metal impurities like Fe, Ni, Cu, Cr etc. are well known to influence semiconductor device parameters like leakage current, gate oxide breakdown voltage etc. The continuous increase of integration density makes present day integrated circuits even more sensitive to metal contaminants as they are recognized as a major yield limiting factor. As integration density increases the tolerable level of metallic impurities is decreasing; most recent reports suggest that the minimal bulk contamination level should be below 10^{11} cm^{-3} 1).

The control of such a low amount of contaminants require improved analytical techniques. The lock-in averaging DLTS 2) is one of the few established investigation tool which sensitivity allows the study of transitional metal impurities in such a low concentration range 3). To perform DLTS however a Schottky barrier or a p-n junction has to be formed and the measurement is rather time consuming. In the recent paper a new improved version of the microwave photoconductivity decay (μ -PCD) 4) measurement is reported which offers a fast, non-contact means to detect qualitatively the lateral distribution map of different metal contaminants in a silicon wafer.

Injection level Spectroscopy

To characterize electrically active impurity levels in semiconductors one has to apply external constrains which would allow the selective filling and emptying of impurity levels. Such an obvious external

constrain is given by the formation of a space charge layer which makes possible the selective filling of the deep levels within the space charge layer by majority or minority carriers and separates in time the carrier capture and the carrier emission processes. Selecting the sample temperature at will carrier emission from any given deep level can be monitored separately. These are the obvious advantages which made Space Charge Layer Spectroscopy 5) (DLTS is one of them) such an indispensable tool for defect characterization.

The price to be paid for selectivity is the necessity to contact the waver. Process control, however requires fast, non-contact survey techniques. Minority carrier diffusion lengths (e.g. SPV 6)) or recombination life time 4) measurements have been introduced for this purpose. In both cases external light source is used to generate non-equilibrium excess carrier and then recombination is monitored by capacitively measuring the change in surface photovoltage or by measuring the change in the microwave reflectivity as the sample conductivity decays back to equilibrium value.

Photoexcitation means the simultaneous injection of electrons and holes and recombination takes place on each deep level present in the sample, i.e. the process is governed by the Schottky-Read-Hall statistics 7) an inherently non-selective physical process. Despite the obvious difficulty several attempts have been reported on GaAs 8) and later on Silicon 9,10) to derive energy level specific informations from the measured temperature dependence of the recombi-

nation lifetime. Unfortunately this approach is based on an unvalid approximation¹¹⁾ which leads to absurd activation energies.

This paper recommends on other path to follow:

Until now it was common knowledge, based upon ASTM recommendations¹²⁾, that minority carrier recombination lifetime as a parameter is defined at low excitation level as (for p type extrinsic material)

$$\tau_o = \tau_{no} \quad (1)$$

where $\tau_{no} = (N_T \sigma_n v)^{-1}$ (N_T is the concentration of the contaminants σ_n is the capture cross section for electrons and v is the drift velocity).

As our detailed analysis has shown¹¹⁾ this approximation is only valid for levels near the midgap and for relatively high shallow doping concentrations.

For levels, near the valence band in p type material, the low excitation level life time is better approximated as

$$\tau_o = \tau_{no} \exp - \left[\frac{(E_T - E_F)}{kT} \right] \quad (2)$$

where E_T is the activation energy of the deep level, measured from the valence band, E_F is the Fermi energy.

At room temperature for the typical Fe-B complex eqn (2) is approximately $\tau_o \approx 100\tau_{no}$ i.e. even at low excitation level for levels which are nearer to the band edge than the Fermi level it is not τ_{no} what is actually measured.

But one has to ask the question: Is that the real purpose to measure τ_{no} ? Our intention is rather to develop a measurement technique which is fast, no sample preparation is needed, sensitive, non-contact, can be used for lateral mapping and the identity of the contaminants can be assessed. We wish to introduce a new quantity which is more characteristic to the impurities, present in the crystal than minority carrier life time. It is recommended to analyze the information content of the response function of the conductivity of the wafer to the injected excess carriers in the function of the injection level:

At high excitation limit

$$\tau_{\infty} = \tau_{no} + \tau_{po} \quad (3)$$

Comparing eqn (1) and (3) it can be seen that for a typical midgap level the life time is decreasing with decreasing injection level, on the other hand from eqn (2) and (3) it follows, that for a level which is nearer to the band edge than the Fermi level the life time is increasing with decreasing injection level. The exact numerically calculated data using the equations from¹¹⁾

are illustrated on Fig.1 for the Fe-B complex

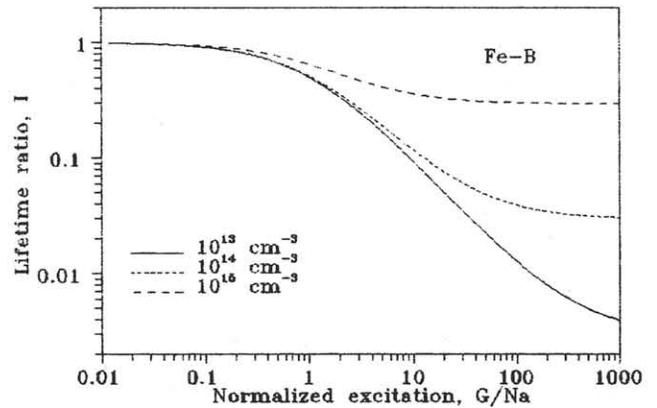


Fig.1 Numerically calculated injection level dependence of the minority carrier life time using the complete form of the Shockley-Read statistics.

This result is in agreement with data from the literature¹³⁾ where it was found, that the high excitation level lifetime is decreasing with increasing Fe-B concentration. For shallower levels the ratio

$$I = \frac{\tau_{\infty}}{\tau_o} = \left(1 + \frac{\sigma_p}{\sigma_n} \right) \exp \left(\frac{E_T - E_F}{kT} \right) \quad (4)$$

can be tabulated for the typical transitional metal impurities in the function of the doping level. This is illustrated for Fe-B, Cr and Au on Fig.2.

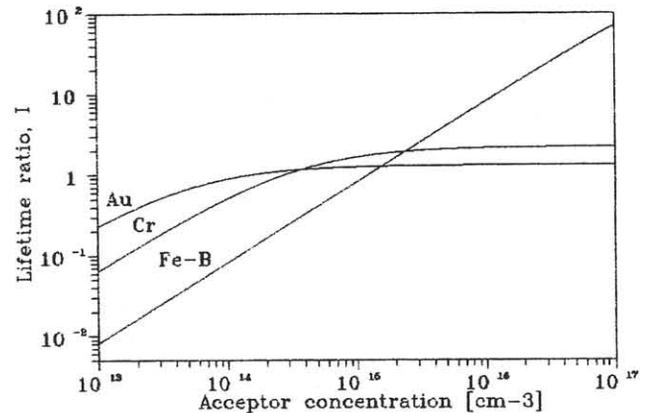


Fig.2 Calculated injection level ratios in the function of shallow doping level.

At a givel temperature and doping level eqn (4) determines a characteristic number for each metallic impurity. And this is what the present paper suggest: Instead of the minority carrier recombination lifetime measured at low excitation level, the ratio of the high and low excitation level lifetime has to be measured. I is characteristic for a given contaminant.

It has to be noted, that if several conta-

minants are simultaneously present at comparable concentration level, an average number will be measured since injection level spectroscopy is not selective in the sense of space charge layer spectroscopy. Measuring, however, the lateral distribution of I one can most probably separate the different contaminants (its highly unlikely that all of them are present in uniform concentration and distribution).

This paper concludes with the experimental verification of this statement. Using a high sensitivity Life Time Scanner based on an improved microwave detection principle¹⁴⁾ CZ silicon wafer, gate oxidized was measured. Fig.3 shows standard wafer map, contaminated from the quartz boat during oxidation.

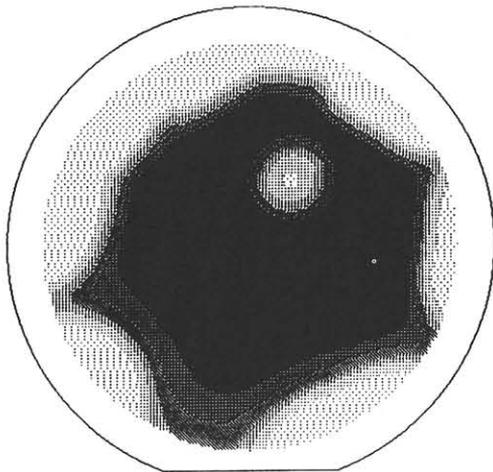


Fig.3 High excitation level lifetime map of a quartz boat contaminated oxidized Silicon wafer life time varies from 0.1 μ s (light area) up to 45 μ s (dark area).

Fig.4, shows how the lifetime histogram changes from high to low level excitation just as our theory predicted. The injection level ratio map is shown on Fig. 5. Beside the point like iron contamination, the iron contamination front is well characterized. The slower diffusing Cr is dominating the perimeter of the wafer.

REFERENCES

- 1) T. Shimono, M. Morita, Y. Muramatu, M. Tsuji, RCVD, 1991
- 2) G. Ferenczi, J. Boda, T. Pavelka, Physica Status Solidi A. 94(1986) K119.
- 3) P. Stallhofer, A. Huber, F. Blöckl, H.Schwenk, ed H.R.Huff, K.G.Barraclough and J.I.Chikawa in Semiconductor Silicon J.Electrochemical Society (1990) 1016.
- 4) A.P. Ramsa, H. Jacobs, F.A. Brand, J. Appl. Phys. 30(1959) 1054.
- 5) D.V. Lang, Thermally Stimulated Relaxation in Solids, Ed: P.Braunlich, Topics in Appl. Phys. 37(1979) 93. (Springer Verlag,Berlin)
- 6) G. Zoth, W. Bergholz, J. Appl. Phys. 67 (1990) 6764.
- 7) W. Schockley, W.T. Read Jr., Phys. Rev. 87(1952) 835.
- 8) Y. Fujisaki, T. Ando, H. Kozuka, Y. Takano, J. Appl. Phys. 63(1988) 2304.
- 9) F. Shimura, T. Okui, T. Kusama, J. Appl. Phys. 67(1990) 7168.
- 10) Y. Kirino, A. Buczkowski, Z.J. Radzinski, G.A. Rozgonyi, Shimura, Appl. Phys. Lett. 57(1990) 2832.
- 11) P. Tüttő, G. Ferenczi, to be published in J. Appl. Phys.
- 12) ASTM Report F 391-78(1979) Annual Book of ASTM Standards, Philadelphia
- 13) H. Lemke, Phys. Status Solidi A. 64(1981) 215.
- 14) J. Boda, G. Ferenczi, P. Horváth, T. Pavelka, Z. Mirk, Hungarian patent application No: 43934/90.

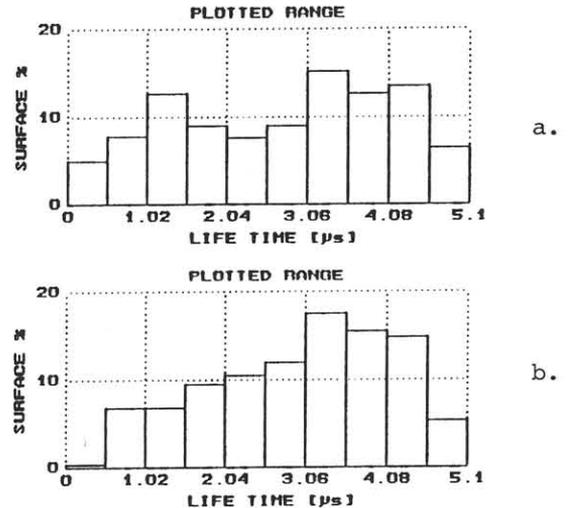


Fig.4 Lifetime distribution
a. high excitation level
b. low excitation level
The change of the distribution is as expected according to calculated values on Fig.1.

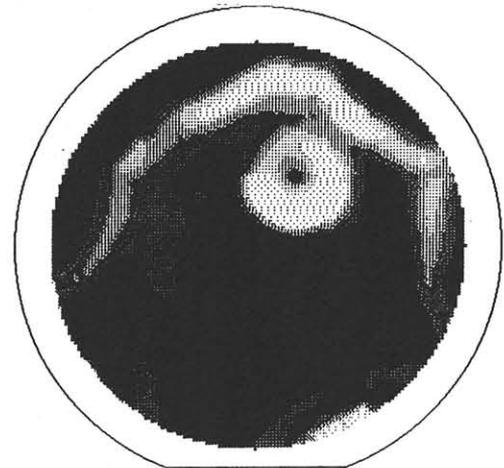


Fig.5 Differential life time distribution map of the same wafer as on Fig.3.