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On the field enhanced carrier generation in MOS structures

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Using a sine voltage sweep C-V, DLTS, gettering and defect revealing techniques the thermal carrier generation in MOS (Metal - Oxide - Semiconductor) structures was investigated. The thermal generation from a field dependent becomes as field independent due to the gettering. The activation energy of generation - recombination centers, E_a, the generation lifetime, τ_g , and Poole-Frenkel factor, α, were determined. Dislocations with an average density of $5 \times 10^6 cm^{-2}$ were observed in all wafers. In the samples with field enhanced carrier generation a linear dependence between E_a and α was found, where the Poole-Frenkel factor increases with the increase of the activation energy. On the other hand E_a , τ_g and α were found to be strongly affected by the gettering, thereby suggesting that they depend on the level of decoration of the dislocations with impurities.

Keywords: MOS; lifetime; defects; gettering.

En este trabajo se usaron estructuras MOS (Metal-Oxido-Semiconductor) para investigar sobre el proceso de generación térmica de portadores apoyada por campo eléctrico en silicio. Mediante la técnica C-V (Capacitancia-Voltaje) con barrido de voltaje senoidal, se determinaron los valores del tiempo de vida de generación, τ_g, y del factor experimental de Poole-Frenkel, α_{exp}. Usando la técnica DLTS (Deep-Level-Transient-Spectroscopy) se encontró la energía de activación, E_a, de los centros efectivos g-r (generación-recombinación). Un revelado químico sobre la superficie del silicio, mostró la existencia de una densidad promedio de dislocaciones de $5 \times 10^6 cm^{-2}$ en todas las obleas usadas. Los resultados obtenidos indican que; cuando a las estructuras MOS se les incluye un proceso de gettering en su fabricación, la generación de portadores es independiente del campo eléctrico. En las muestras sin proceso gettering, la generación de portadores es apoyada por campo eléctrico y se observó una dependencia lineal entre, el factor de PF y la energía de activación de los centros g-r. A medida que se incrementa el valor de α , los centros g-r se sitúan mas cerca de la mitad de la banda prohibida (α se incrementa). Por otro lado, el proceso gettering realizado a las obleas, influye fuertemente sobre los valores de los parámetros E_a, α y τ_g medidos de las diferentes estructuras MOS. Suponemos que los valores de esos parámetros dependen del nivel de decoración con impurezas en las dislocaciones.

Descriptores: MOS; tiempo de vida; defectos; gettering.

PACS: 73.40.Ty; 73.25.+1

1. Introduction

The generation processes of minority carriers in the Space Charge Region (SCR) of the semiconductors have been extensively investigated in recent years employing MOS capacitors. Most of the methods used to determine the generation lifetime are based on the response of a MOS capacitor to a deep depleting voltage step [1, 2] or, to a voltage sweep [3, 4]. In all these methods a linear dependence between the carrier generation and the width of the depletion region is predicted (Zerbst plot, Fig. 1). However, in many cases a non-linearity of this dependence and an enhanced carrier generation corresponding to large depletion widths has been observed [1, 2, 5–7]. The one-dimensional Poole - Frenkel model was used to explain this enhanced thermal generation [2]. The Poole - Frenkel (P-F) model [8] describes how the ionization processes of coulombic type centers are affected by an applied electric field. It assumes a decrease of the activation energy, ΔE_a , of this type of centers, with respect to the initial value E_a , as a result of a lowering in the potential barrier due to an applied electric field. According to the one dimensional P-F model the electron emission rate is a field dependent as

$$e_n = e_n(0)exp(\alpha\sqrt{F}), \tag{1}$$

where $e_n(0)$ is the thermal emission rate at zero electric field, α is the P-F factor and F the electric field.

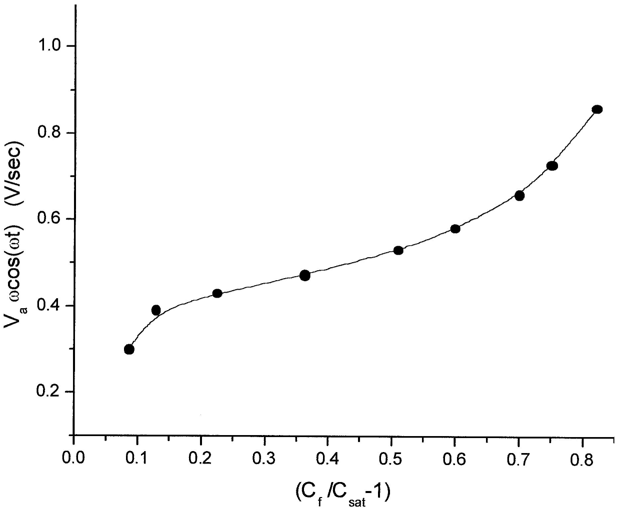

FIGURE 1 Tipical Zerbst plot from a MOS capacitor used in our experiments (wafer P1).

When minority carrier generation in the Space Charge Region (SCR) is controlled by electron emission from the coulombic centers, the generation lifetime τ_g , is also field dependent as inverse of Eq. (1),

$$\tau_g(F) = \tau_g(0)exp(-\alpha_{th}\sqrt{F}), \tag{2}$$

where, $\tau_g(0)$ is the generation lifetime for $F = 0$, α_{th} is the theoretical P-F factor (in silicon at $300K$ has a value of 0.0085 $(cm/V^{1/2})$. However, the experimental value of this factor, α_{exp}, can be quite different from the theoretical one [9–12]. It was suggested [9] that the local electric fields near to defects are responsible for such deviation of α from its theoretical value. The expression for the local electric field is given by [9]

$$F_{loc} = \left(\frac{\alpha_{exp}}{\alpha_{th}}\right)^2 F_{max}, \tag{3}$$

where F_{max} is the maximum electric field in the SCR.

Small and Pierret [5] assumed that local electric fields depend on the density of defects. Werner et al. [9] have found a field enhanced carrier generation in samples with low generation lifetime, while local electric fields were assumed in samples with high density of defects and very low ($\approx 1\mu sec$) generation lifetime.

However, it has been suggested [10–12] that the field enhanced carrier generation and the local electric fields, besides on the concentration of defects, depend to great extent on the type of defects, the type of impurities and the level of decoration. The type of defects can be different. They can be point or extended defects. On the other hand extended defects can be clean or decorated with different type of impurities. That is why the activation energy of extended defects related deep centers depends on the level of decoration and the type of impurities.

In this paper a series of experiments performed on MOS capacitors having gettering process are described. The role of impurity decoration on the properties of extended defects is investigated. We determined generation lifetime, τ_g, and the experimental P-F factor, α_{exp}, from MOS structures. Also the activation energy, E_a, of the deep centers by DLTS technique was founded. These parameters were correlated with posgettering annealing time.

2. Experimental Details

The experimental procedure was conducted on CZ grown, 2.5 - 5 Ωcm, (100) oriented, n-type Si wafers, and labeled $P1$ - $P6$. After a preliminary RCA cleaning, the samples were oxidized at $1000\ ^\circ C$ in dry $O_2 + 2\%$ TCA$(C_2H_3Cl_3)$ until $800\ \AA$ oxide thickness was obtained. Afterwards they were annealed in dry N_2 for 30 min. at the same temperature. The final oxide thickness was measured by an ellipsometer. A phosphorous diffusion at $1050\ ^\circ C$ for 20 min. on all the wafers, except $P1$, as gettering process was carried out. Wafers $P2$, $P3$, $P4$, $P5$ and $P6$ were annealed in dry nitrogen at $900\ ^\circ C$ for 30, 60, 90, 120 and 150 min. respectively. After the PS glass from the backside of the wafers was removed, MOS capacitors were performed by evaporation of aluminum through a metal mask on the top oxide of all wafers. Additionally, aluminum was evaporated onto the backside of the wafers. Finally, all wafers were annealed in N_2/H_2 $(60 : 40)$ ambient at $425\ ^\circ C$ for 30 min.

The sine-voltage sweep C-V method was used to get the Zebst plot (see Fig. 1) [4]. Generation lifetime, τ_g, and the experimental P-F factor, α_{exp} were extracted from such Zerbst plot. The capacitance was measured with a Boonton 72 capacitance meter and a Wavetek 271 function generator was used as a voltage source. A Bio-Rad 4600 DLTS system was used to characterize the deep levels. The DLTS scan was done with a bias of $-1.5V$ and a filling pulse from -1.5 to $0V$. Non-exponential transient was observed for all of the measured devices and their DLTS spectrum shown the broad band typical in samples containing dislocations and/or $OSFS's$ (Oxidation Stacking Fault) [13–16]. After the electrical measurements were completed the aluminum dots and the oxide of MOS capacitors were removed and the defects were revealed by a chemical etching [17]. The type and the density of defects were determined by an optical microscope.

3. Experimental Results And Discussion

The plots of τ_g and E_a as function of annealing time are shown in Fig. 2. The annealing is an important step in the processes of gettering. During this step, the impurities are released from their trapping sites, diffuse towards the sink (the damage layer at the backside of the wafer) and are trapped there. According to the behavior of τ_g and E_a, as a function of the annealing time, these plots can be divided in 3 regions. α_{exp} corresponding to each region is also given in Fig. 2. In the region I $\alpha_{exp} > \alpha_{th}$, while in the regions II and III, $\alpha_{exp} = 0$. In other experiments [18, 19] it has been found that α_{exp} decreases slower with the annealing time. Evidently, the rate of change of α_{exp} with the annealing time depends on the gettering efficiency, i.e., on the annealing conditions, the type of the gettering processes and the type of the impurities.

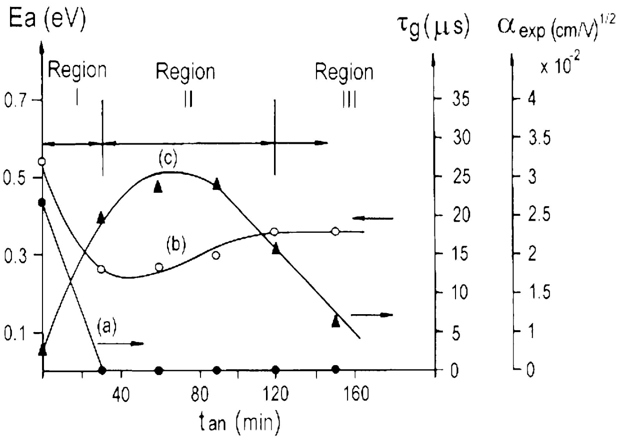

FIGURE 2 Behavior with respect to the annealing time; activation energy, E_a (○ ○ ○), generation lifetime, τ_g (△△△), and experimental P-F factor, α_{exp} (● ● ●) .

Defects in the Si wafers were determined to be dislocations with an average density of $5 \times 10^6 cm^{-2}$ in each wafer. The very low generation lifetime, the high activation energy and $\alpha_{exp} > \alpha_{th}$ in the region I suggest that the generation is controlled by deep coulombic type centers, influenced by local electric fields. We suppose that in this region the energy levels are introduced by the dislocations decorated with impurities.

It has been reported [5] that a field enhanced carrier generation is likely to occur from bulk centers related to defect sites where large electric fields exist. It has been found that the extended defects when decorated with metallic impurities show drastically enhanced field dependent generation rate [9–12, 20] and its energy level moves towards the midgap [15, 21].

In region I, there is a strong correlation between the activation energy of generation centers on the local electric field as can be seen from Fig. 3. Taking into account that α_{exp} becomes equal to 0 (regions II and III) due to the annealing , the linear relationship found between E_a and α_{exp} demonstrates that E_a and the local electric field depend on the amount of impurities on the dislocations.

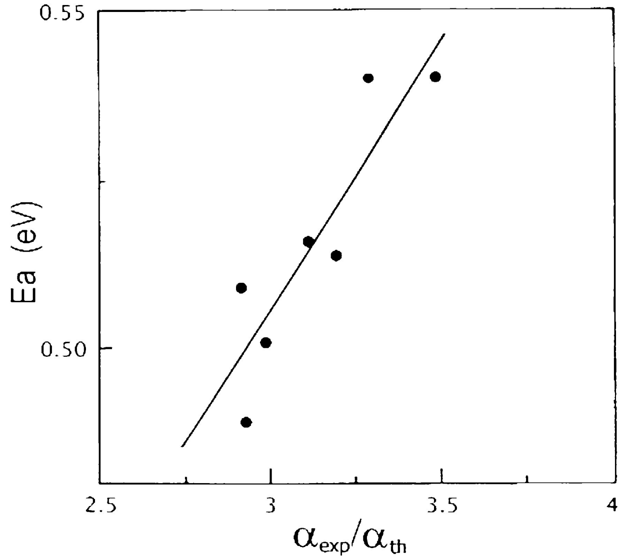

FIGURE 3 Experimental plot of E_a vs. $(\alpha_{exp}/\alpha_{th})$. Points measured from wafer P1.

Different factors can be responsible for the existence of high electric fields in the vicinity of defects. For instance, high electric field exists in the SCR around a dislocation. The radius of the SCR depends on the doping level and the trapped charge. The latter depends on the number of dangling bonds and the activation energy of the deep center, which is a function of the type and amount of impurities on the dislocation. The applied voltage also affects the SCR. On the other hand, it is well known that dislocations act as nucleation centers for metallic and dielectric precipitates such as SiO_2 . It has been reported [22, 23], on the existence of high electric fields related to SiO_2 precipitates which cause preferential microplasma breakdown in reverse biased junction. The microplasmas appear as small spots of light emission.

As the annealing time increases, the level of decoration decreases due to the gettering, and the activation energy of the centers decreases. Therefore, in agreement with the Shockley - Read statistics [24], the generation effectiveness decreases and as a consequence the generation lifetime increases. In the region II where $\alpha_{exp} = 0$ (field independent generation), τ_g reaches its maximum and E_a reaches its minimum. This means that metallic impurities, at least these ones responsible for the field enhanced carrier generation and local electric fields, are gettered away, leaving ”clean” dislocations in the SCR.

One can be tempted to associate the minimum activation energy in the region II with the clean dislocations. Several authors reported energy levels related to the clean dislocations [13, 16, 25], however, it has been reported that these levels are probably associated with impurities decorating the dislocations, even though the decoration is inadvertent [14].

In the region III, α_{exp} is also equal to 0, but the generation lifetime decreases with the increase of the annealing time, while the activation energy increases until $0.37 eV$ is reached and after that it is a constant.

Kveder et al. [16], have found in Si samples containing dislocations, that the EPR signal of the DE_2 center with an energy at E_c - $0.37eV$ is slightly increased after an annealing.

We think that for long annealing times (region III), there is an interaction between dislocations and inadvertent impurities, other than gettered ones, which result in introducing of non-coulombic type centers. It has been shown [26, 27], that the most probable reason for the degradation of generation lifetime in MOS structures for long annealing times is a metallic contamination from the annealing ambient.

4. Conclusions

The influence of gettering on the generation properties of MOS structures has been investigated. Dislocations with an average density of $5 \times 10^6 cm^{-2}$ has been observed in all the wafers. It has been found that the thermal carrier generation from a field dependent becomes field independent as result of the gettering. Assuming the existence of local electric fields in the vicinity of defects, the field enhanced carrier generation was explained by the one-dimensional Poole-Frenkel model.

A close relation between E_a , τ_g , α_{exp} and the post gettering annealing time has been observed. This suggests that dislocations introduce deep levels with activation energy depending on the level of decoration and the type of impurities. A linear dependence between E_a and α_{exp} has been found. The P-F factor increases with the increase of the activation energy. This means that E_a and the local electric fields are closely related to the amount of impurities on the dislocations. We think that local electric fields can be originated from extended defects decorated with different inclusions such as metallic impurities or precipitates, SiO_2 precipitates or complex of oxygen with metallic impurities.

It has been shown that the gettering can be a useful tool in the investigation the role of impurity decoration in the properties of extended defects.

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