La estructura MOS como sensor de flujo de fotones

The MOS structure as photon flux sensor

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Resumen.

En este trabajo se usó el método de barrido de voltaje senoidal para medir la densidad del flujo de fotones, usando una estructura MOS (metal-óxido-semiconductor). Se realizó un análisis teórico que soporta los resultados experimentales. Se encontró que la relación entre la densidad de flujo de fotones y la capacitancia de saturación es lineal, aun cuando se presente generación apoyada por campo eléctrico, es decir, esta medición es independiente de la naturaleza de los defectos en el semiconductor. Resultado muy importante, que permite la fabricación de sensores de luz con base a las estructuras MOS.

Palabras Claves: MOS, fotones, flujo, generación, defectos

Abstract.

In this work the sine voltage sweep method was used to measure the density of photon flux using MOS structures. A theoretical analysis was done in order to support the experimental results. It was found that the relation between photon flux density and saturation capacitance is lineal, even when, field enhanced carrier generation is present, it's like, this measurement is independent from the nature of the defects in the semiconductor. A very important result that allows the making of light sensor based on MOS structures.

Key words: MOS, photon, flux, generation, defects.

1 Introducción

The MOS structure in depletion or inversion condition is very sensitive to light. This property is used to develop and made couple charge devices (CCD) as image sensors in solid state .

The photoelectrical properties of these structures are used to make photodiodes arrangements and photoelectrical devices with better efficiency conversion than union devices (pn) . The application of this effect has been extended to the measurement of the diffusion length] and the determination of generation lifetime .

A possible application of the MOS devices is the measurement of the photon flux density. This device could be integrated as sensor in integrated circuits (IC).

Photon flux measurements using voltage pulse method, require the knowledge of the impurity concentration N_B, however, a mistake on its value affects directly on the final result . This is important; due to N_B could not be a constant, especially on the Space Charge Region (SCR), due to the distribution of impurities during the oxidation process.

In the present work, we show in theoretical and experimental way, how is possible to measure the photon flux density using the sine voltage sweep method, avoiding the inconvenient mentioned above in using others techniques. We also show that photon flux measurement is independent of the defects and/or impurities not desired in the semiconductor.

2 Theory

Let's consider a MOS capacitor with n – type substrate, in which we apply a voltage in form of

$$V(t) = V_{of} + V_a \operatorname{sen} \omega t \tag{1}$$

where, V_{of} is the offset voltage, V_a the amplitude, ω is the angular frequency and t the time. If the applied voltage is negative and its change rate is higher enough to take the device to the deep depletion condition, the capacitor will tend to the inversion condition as result of the thermal process and external generation of electron-hole pair (ehp), through one of the following mechanisms:

1) Thermal generation in the interface Si-SiO_2
2) Thermal generation in the SCR.
3) Thermal generation in the quasi-neutral volume region.
4) Thermal generation in the quasi-neutral surface.
5) External generation (through photons incidence, high-energy electrons, etc.).

At room temperature, for the silicon, the dominant generation processes are:

$$G_1 = \frac{n_i}{\tau_g}\left(W - W_{inv}\right) \tag{2}$$

and

$$G_2 = n_i S \tag{3}$$

where G_1 and G_2 are the volumetric generation and the surface generation respectively, W the width of SCR, W_{inv} is the width of the SCR in inversion condition, n_i the intrinsic concentration, S the surface generation velocity and τ_g the generation lifetime. If the emission of electrons is controlled from coulombic centers in the depleted layer, the carrier generation is field dependent and equation (2) is replaced by:

$$G(E) = G_1 \exp\left(\alpha\sqrt{E}\right) \tag{4}$$

here, α is the Poole-Frenkel factor and E the electric field in the semiconductor.

In presence of an external excitation, the effective generation of electron-hole pairs is done within a diffusion length, L_n, from the SCR. Under optical excitation, the rate of ehp´s generation is given by:

$$G_5 = \eta N_{ph} \tag{5}$$

where N_{ph} is the photon flux density and η is the quantum efficiency.

As was stated in, for the silicon at room temperature, the equation:

$$\frac{C_{ox}}{q} R = G_1 + G_2 \tag{6}$$

is valid. Here C_{ox} is the oxide capacitance, q is the electron charge and R is the voltage sweep rate.

Substitution of equations (2) and (3) in (6) and using the relation $W = \varepsilon_s (C^{-1} - C_{ox}^{-1})$ we get;

$$\frac{C_{ox} R_{sat}}{q} = \frac{\varepsilon_o \varepsilon_s n_i}{C_{inv} \tau_g}\left[\frac{C_{inv}}{C_{sat}} - 1\right] + n_i S \tag{7}$$

where C_{sat} is the saturation capacitance, R_{sat} is the sweep rate in the saturation point, ε_o is the permittivity in the vacuum and ε_s is the silicon dielectric constant.

In optical excitation presence and neglecting the surface generation , the equation (7) can be expressed as:

$$\frac{C_{ox} R_{sat}}{q} = \frac{\varepsilon_o \varepsilon_s}{C_{inv}^1 \ \tau_g}\left[\frac{C^1{}_{inv}}{C^{\ 1}{}_{sat}} - 1\right] + \eta N_{ph} \tag{8}$$

here, the super index "1" refers to the optical excitation case and ηN_{ph} is the optical generation.

Doing measurements on illumination and darkness conditions, with a rate value of R_{sat} we can use the equations (7) and (8) to obtain the photon flux density;

$$N_{ph} = \frac{\varepsilon_o \varepsilon_s n_i}{\eta \tau_g}\left[\frac{1}{C_{inv}^d}\left[\frac{C_{inv}^d}{C_{sat}^d} - 1\right] - \frac{1}{C_{inv}^1}\left[\frac{C_{inv}^1}{C_{sat}^1} - 1\right]\right] \tag{9}$$

where the super index "d" refers to the darkness measurement case (normal conditions). The use of equation (9) to determinate the photon flux density depends on the C-V curves obtained, first, on darkness conditions and after that, under lighting.

3 Samples Preparation.

MOS capacitors were fabricated on (100) oriented n-type (2.5 Ω-cm), CZ grown Si wafer (labeled P wafers) and (111) oriented, Si wafers n/n^+ (2.5/0.01 Ω-cm) and 10μm thick epitaxial layer (labeled EPI wafers). Previous to oxidation all wafers were treated in a standard RCA process to eliminate moisture on the surfaces of the sustrates.

After that, the wafers were oxidized at 1000°C in dry O_2 + 2% TCA ($C_3H_3Cl_3$) to obtain 800 Å of oxide thickness. Later, they were annealed in a N_2 environment for 30 minutes at the same temperature. The oxide was removed from the back of the wafers.

An ion phosphorous implantation with 90keV of energy and a dose of 10^{16} cm^{-2} was performed on the backside of the wafers (except to P1 and EPI1). The post implantation annealing times for P2, EPI2, P3, EPI3, P4, EPI4, P5, EPI5, P6 and EPI6 were 0, 0, 30, 30, 60, 60, 90, 90, 120 and 120 minutes respectively at 900 °C in N_2 ambient.

Aluminium dots for MOS capacitors were deposited through a metal mask on the top oxide. On the backside of the wafers, aluminum was also evaporated. The area of the dots was $5.3x10^{-3}$ cm^2. Sustrates were sintered at 425 °C in H_2/N_2 (10/40) for 30 min.

A Boonton 72b capacitance meter, a Wavetek 271 function generator and a x-y recorder were used to draw the C-V high frequency curves.

4 Results

High frequency characteristics C-V from MOS capacitors on the darkness condition are presented in figure 1(a). From those C^d_{sat}, C^d_{inv} and τ_g can be determinate. Curves in figure 1(b) were drawn for the same capacitor, but in each one of them under different intensities of illumination, to obtain the parameters C_{inv} and C_{sat}.

In table 1, the N_{ph} values obtained under the different values of lighting intensity are presented.

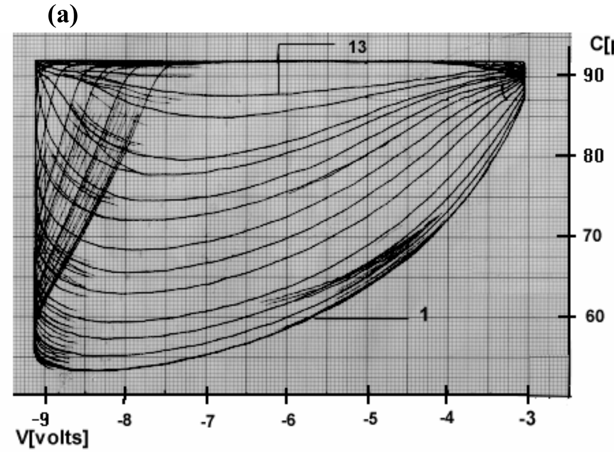
Table 1. Values extracted from the C-V curves obtained under optical excitation for a capacitor from wafer P6 with τ_g=1.31μs.

Curva	C^1_{sat} [pf]	C^1_{inv} [pf]	Nph X10^{11} [ph/cm^2seg]
1	53.3	91.8	
2	55.1	91.8	0.58
3	57.3	98.1	1.23
4	59.4	98.1	1.82
5	63	98.1	2.72
6	65	98.1	3.19
7	68.4	98.1	3.9
8	72.1	98.1	4.61
9	74.5	98.1	5.03
10	77.7	98.1	5.55
11	79.5	98.1	5.82
12	84.9	98.1	6.58
13	87.5	98.1	6.91

From table 1 as base, N_{ph} vs C_{sat} plots (fig. 3) were sketched. As can be seen, the relation between them is lineal; this means that the decrease of the SCR is proportional to the measurement of the photon flux density. As were stated by authors [9,10,11], the influence of the defects and/or impurity in the interface Si-SiO_2, depends on the initial and final conditions in the polarization. With respect to the volume of the semiconductor, it's known that the association extended defect-metallic impurity introduces columbic R-G centers, which cause a deviation in the linearity of the generation curves in accordance with the equation (4).

To know the influence on the measurement of the photons flux density, we realized the experiment described above, but now with a sample that present this effect.

(a)



(b)

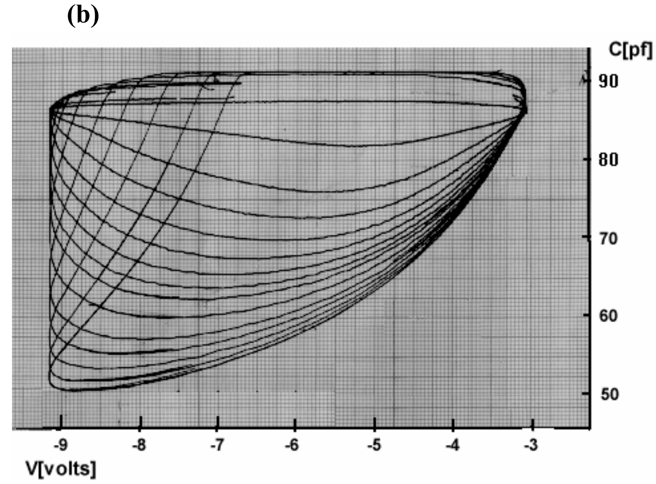
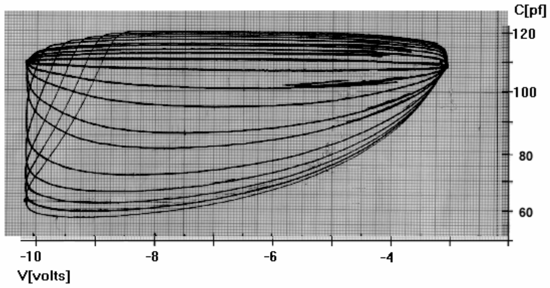


Fig. 1. Curves family C-V for a capacitor of the wafer P6 (a) in absence of external excitation to obtain the value of τ_g with V_a=3.045V and sweep frequencies of 10, 20, 30, 40, 50, 60, 70, 80, 100, 130, 160, 200, 250 and 300 mHz, and (b) under different lighting intensities with f=200 mHz, to obtain the photons flux density.

(a)



(b)

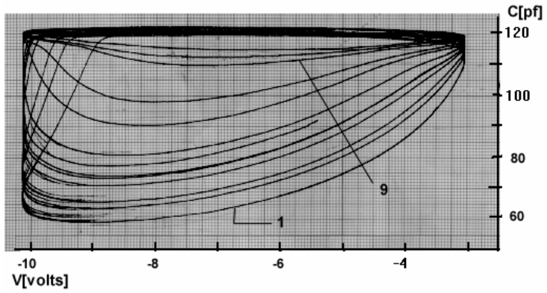


Fig. 2. Family of C-V curves for a capacitor from the wafer EPI5 (a) in absence of external excitation to obtain the value of τ_g with V_a=3.157and sweep frequencies of 10, 30,50,80,100,150, 200,250,300 and 350 mHz and (b) under different intensities of lighting.

In fig.2 the C-V curves for a capacitor from the wafer EPI5 in darkness and lighting condition are presented. Zerbst plot is drawn (fig. 4) and an increase in the generation rate in the high electric field is observed (acording eq. (4)). Using the values in table 2, we obtain the relation between photon flux density and the capacitance of saturation (fig. 3) we observe that this relation is still being lineal, even when field enhanced carrier generation is present

Table 2. Values for C^{l}_{sat} and C^{l}_{inv} obtained from C-V curves (for a capacitor from the wafer EPI5) under lighting condition, here τ_g=1.51µs. N_{ph} was calculated from eq. (9).

Curva	C^1_{sat} [pf]	C^1_{inv} [pf]	N_{ph} x 10^{11} [ph/cm^{2}seg]
1	59.0	119.7	
2	63.4	119.8	2.63
3	65.6	120.2	3.77
4	71.0	120.5	6.35
5	73.3	120.8	7.31
6	80.9	121.1	10.16
7	90.3	121.3	13.05
8	98.0	121.4	15.01
9	109.8	121.8	19.46

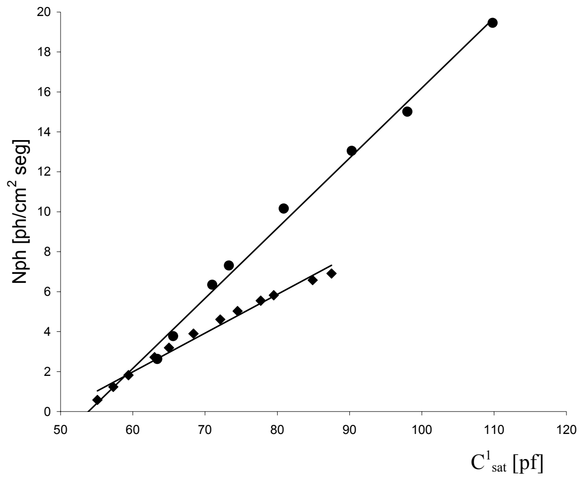


Fig. 3. Behavior of photo flux density N_{ph} as function of the saturated capacitance C_{sat}. For a capacitor from the wafer P6 (♦) and for a capacitor from the wafer EPI5 (•).

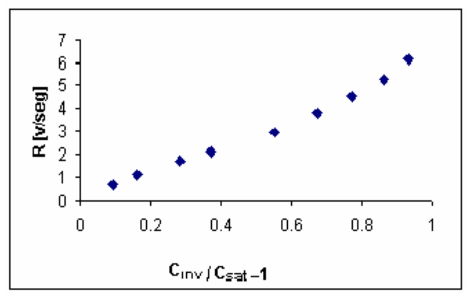


Fig. 4. Zerbs plot for a MOS capacitor from the wafer EPI5.

5 Conclusions.

The sine voltage sweep method was used to measure the photon flux density avoiding the inconvenient in using other techniques. A theory that supports the experimental results was presented, and it was shown that independently of the nature of the extended defects in the semiconductor, the relation between photon flux density and the capacitance of saturation is lineal. A result very interesting because it allows including as a sensor element in integrated circuits IC.

6 References

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