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Improving Sensitivity of p-n Junction Temperature Sensor by Carrier Lifetime Modification

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Abstract. This paper presents the relation between the staring cobalt thickness with carrier generation lifetime, which effects to the sensitivity of p-n junction temperature sensor. The starting cobalt thickness of 12, 20 and 30nm have been used. The carrier generation lifetimes have been calculated from the reverse current-voltage (I-V) characteristics. The highest carrier generation lifetime has been obtained in the case of 12nm starting cobalt thickness. The highest sensitivity of p-n junction temperature sensor has also been observed from the case of 12nm starting cobalt thickness. The sensitivity has been calculated from the relation between leakage current versus temperature. The sensitivity of p-n junction temperature sensor can be improved by increasing carrier generation lifetime.

Introduction

Several techniques have been developed to improve sensitivity of p-n junction temperature sensor. One way among others is to improve carrier lifetime. This carrier lifetime can be modified by many approaches, such as diffusing gold [1] or platinum [2]. For downscaling CMOS technology, cobalt silicide has been used to reduce series resistance[3]. During silicidation step, cobalt atom can also diffuse deeper to junction. Among of cobalt atom and depth can be controlled by process conditions, such as starting cobalt thickness and temperature [4]. This effects to the generation lifetime [5], which may relate to the sensitivity of p-n junction temperature sensor. Therefore, this paper will present the relation between the generation lifetime and the sensitivity of p-n junction temperature sensor.

Experimental

Shallow n^+-p junction diodes compatible with CMOS technology are processed on 150 mm diameter p-type Cz wafers. The doping density is in the range of 10^{15} cm^{-3}, as derived from capacitance-voltage (C-V) measurements on the reverse biased junction. The n^+ region have been fabricated by a 70 keV, 3x10^{15} cm^{-2} arsenic implantation followed by a 1100 ^{o}C, 10 s rapid thermal anneal. This results in a junction depth in the range of 0.17 to 0.2 µm. Splits with different Co thickness, 12, 20 and 30 nm have been processed. The non-silicided reference wafer has been contacted by standard Al metallization. Lateral isolation of the diodes is achieved by a classical LOCOS (LOCal Oxidation of Silicon) scheme.

Current-voltage (I-V) and Capacitance-voltage (C-V) characteristics are performed on wafer of a large area (Area=0.1 cm^2, Perimeter=1.3 cm) and a long perimeter (Area=0.001 cm^2, Perimeter=8.04 cm) junctions. The variable forward or reverse bias is applied to the back ohmic contact, while the current is measured at the top junction contact. The substrate temperature has been varied from 25 ^{o}C to 120 ^{o}C. The generation lifetime has been calculated from the I-V and C-

V characteristics. The sensitivity of p-n junction temperature sensor has been obtained from the slope of the reverse current versus temperature.

Results and Discussion

I-V characteristics of a large area (SQ1) and long perimeter (ME1) diodes without and with different cobalt silicide thickness are shown in Fig. 1. The forward and reverse current of both SQ1 and ME1 are in the same order of magnitude. The forward and reverse (leakage) current increase with an increasing cobalt silicide thickness in both SQ1 and ME1 junctions. Theoretically, the leakage current (I_R) consists of the diffusion (I_{diff}), bulk generation ($I_{gen,b}$) and surface generation ($I_{gen,S}$) current. As a result, one can write for I_R [6,7,8]:

$$I_R = I_{diff} + I_{gen,b} + I_{gen,S} \tag{1}$$

$$I_{diff} = qn_i^2 A\left(\frac{D_n}{L_n N_A} + \frac{D_p}{L_p N_D}\right) \tag{2}$$

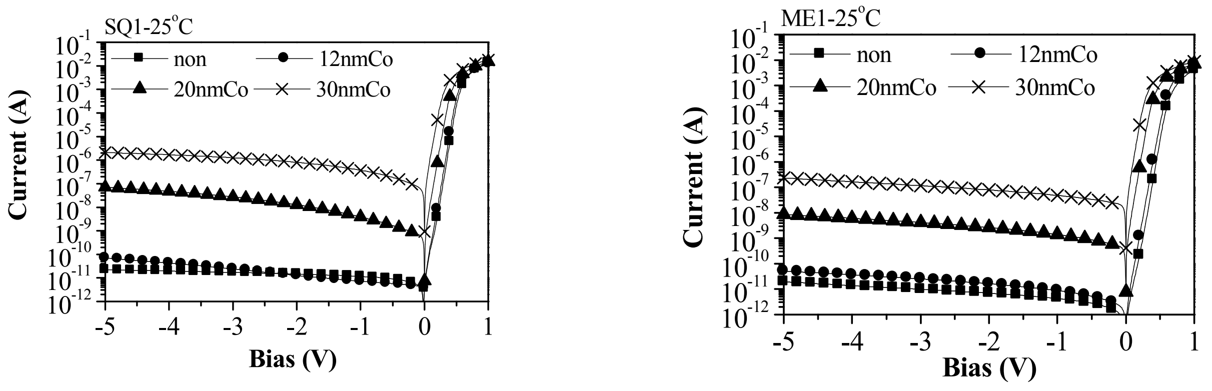
$$I_{gen,b} = \frac{qn_i WA}{\tau_g} \tag{3}$$

$$I_{gen,S} = qn_i SA_S \tag{4}$$

$$n_i = 1.640x10^{15}T^{1.706}\exp\left(-\frac{E_g}{2kT}\right) \tag{5}$$

$$E_g = 1.17 - \frac{4.73x10^{-4}T^2}{(T+636)} \tag{6}$$

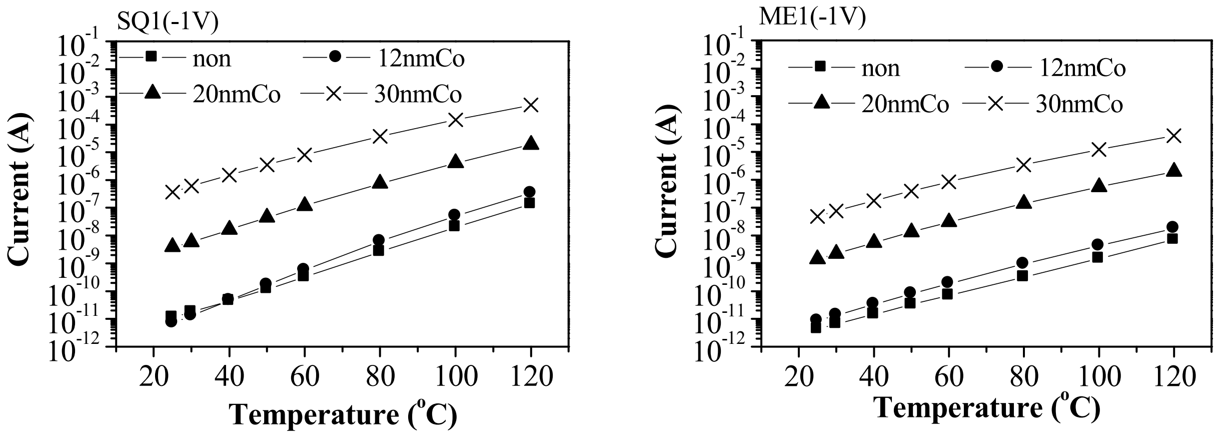
where D_n and D_p are the diffusion coefficient of electrons in the p-side and holes in the n-side, respectively, L_n and L_p are the electron and hole diffusion length, q is the electron charge, n_i is the intrinsic carrier concentration, A is the junction area, W is the depletion width, τ_g is the generation life time, S is the surface recombination velocity of the minority carriers at the Si-SiO$_2$ interface, A_s is the junction periphery space charge region, k is the Boltzmann constant, T is the absolute temperature and E_g is the bandgap of the material.



(a) (b)

Fig. 1 I-V characteristics of (a) large area SQ1 and (b) long perimeter junction without and with different Co silicide thickness.

From (5), n_i is temperature dependent. This can be expected that the diffusion current in (2), the bulk generation current in (3) and the surface generation current in (4) increase with temperature. The leakage current in (1) is foreseen to increase with the temperature. As shown in Fig. 2, the leakage current at -1V versus temperature exponentially increases with the temperature in both SQ1 and ME1 in all caseses with and without cobalt silicide. In SQ1, the leakage current at high temperature is not bias dependent. This is pointing that the leakage current is dominated by the diffusion component. This is not the case for low temperature. The leakage current is bias dependent, which shows the generation current component dominant the leakage current. In case of ME1, the leakage current is bias dependent in study temperature range. This means the leakage current is dominated by the surface generation current component. The leakage current in ME1 is less bias dependent at high temperature. This relates to the increasing of the diffusion current component. From (2-4), the diffusion current is higher temperature dependent than the bulk and surface generation current. Figure 2 is also indicated that the higher slope can be expected for the leakage current dominant by generation current. Therefore low reverse bias voltage will be used to study the effect of cobalt silicide to the sentivity of p-n junction temperature sensor later.



(a) (b)

Fig. 2 Leakage current of of (a) large area SQ1 and (b) long perimeter junction without and with different Co silicide thickness at -1V and -5V.

From Fig. 2, it can be interpreted that the sensitivity of the p-n junction as temperature sensor can be found from the slope of the semi log plot between leakage current and temperature. The results are shown in Fig. 3. The highest coefficient has been obtained in case of 12nm cobalt thickness for both SQ1 and ME1 junction. The higher coefficient is found for SQ1 than ME1 junction. This is due to the dominant of diffusion current. The temperature coefficient in SQ1 reduces with higher reverse bias, which relates to the dominant of bulk generation current. A higher temperature coefficient has been observed in SQ1 than ME1. From above results, it can be interpreted as following. The highest temperature coefficient will be found in the p-n junction that the leakage current is dominated by the diffusion current component. A higher coefficient is foreseen form p-n junction temperature sensor which the leakage current is controlled by the bulk generation current than the one is rules by the surface generation current.

For the large area junction the surface generation current is expected lower than the diffusion and bulk generation current. Then the leakage current in (1) should be constant if it is dominated by the diffusion current. While the leakage current is expected to be increase with reverse bias voltage if it is dominated by the bulk generation current. In case of the bulk generation current dominates the leakage current, it should be proportion with the depletion width. From (3), the generation lifetime can be calculated from

$$\tau_g = \frac{q n_i W A}{I_{gen,b}} \tag{7}$$

The generation lifetime versus depletion width of diodes without and with different cobalt silicide thickness are shown in Fig. 4. The highest generation lifetime was found in the 12nm cobalt thickness. The lowest generation lifetime has been observed in the case of 30nm cobalt thickness. This confirms that the temperature coefficient can be increased by lowering the generation current by increasing generation lifetime.

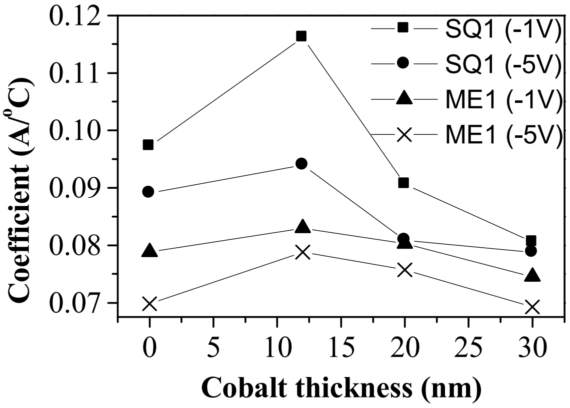


Fig. 3 Coefficient of SQ1 and ME1 junction without and with cobalt silicide of leakage current at -1V and -5V.

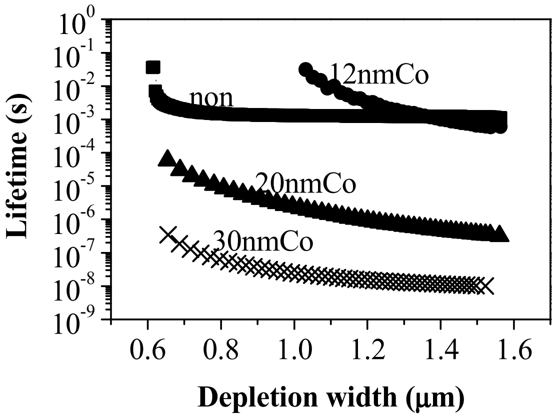


Fig. 4 The generation lifetime versus depletion width of junction without and with cobalt silicide.

Summary

The highest sensitivity of p-n junction temperature sensor is found in the devices that has the highest generation lifetime. This is due to the dominant of the diffusion current in the leakage current. This implies that the sensitivity of p-n junction temperature sensor can be improved by reducing the generation current. This can be achieved by increasing generation lifetime.

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