Analysis of Oxygen Thermal Donor Formation in n-type Cz Silicon

J.M. Rafí[1*], E. Simoen[1], C. Claeys[1,2]
A.G. Ulyashin[3], R. Job[3], W.R. Fahrner[3]
J. Versluys[4], P. Clauws[4]
M. Lozano[5] and F. Campabadal[5]

[1] IMEC, Kapeldreef 75, B-3001 Leuven, Belgium
[2] also at KUL, E. E. Dept., B-3001 Leuven, Belgium
[3] University of Hagen, Electr. Eng. Dept.,
Haldener Str. 182, D-58084 Hagen, Germany
[4] University of Ghent, Dept. of Solid-State Sciences,
Krijgslaan 281 S1, B-9000 Gent, Belgium
[5] Institut de Microelectrònica de Barcelona (CNM-CSIC),
Campus UAB, E-08193 Bellaterra, Spain

Introduction

By now, it is a well-accepted fact that hydrogen plays a catalytic role in the formation of thermal donors in Czochralski (Cz) silicon (1). Hydrogen can be introduced in several ways in the material, among which hydrogen plasma treatment is of strong interest owing to its low cost, high throughput and low thermal budget (2). Combining a low temperature plasma hydrogenation, followed by a relatively short thermal donor anneal at 450°C, it has been demonstrated that p-type starting material can be converted into n-type silicon and that, therefore, deep p-n junctions can be obtained in a fast and cheap way (2,3). The depth of the junction is thereby controlled by the hydrogen in-diffusion profile (3). So far, most studies have focused on p-type Cz starting material. Here, the impact of the plasma hydrogenation time on the thermal donor (TD) formation during an anneal at 450 °C from 30 min up to 50 h in n-type Cz material is investigated. It is shown by Capacitance-Voltage (C-V) and Spreading Resistance Probe (SRP) profiling that there is indeed an enhancement of the TD formation rate. Surprisingly, initial Deep Level Transient Spectroscopy (DLTS) results indicate only a donor level at E_c-0.12 eV, with a concentration which is only 10 % of the donor concentration increase.

Experimental

The n-type Cz starting material has a doping concentration of 10^{15} cm^{-3} and an interstitial oxygen concentration $[O_i]$ of 7 to $8x10^{17}$ cm^{-3}. Plasma hydrogenation was performed at 250°C using the conditions previously described and for 30, 60 or 120 min (2,3). Next, a TD anneal at 450°C was executed in air for a time t between 30 min up to 50 h. Reference samples with only H-plasma or 450°C TD anneal have also been prepared. The carrier concentration profiles were measured by SRP. High-frequency C-V measurements were performed on 3 mm Au Schottky barriers, which were evaporated on a wet-etched surface to remove the plasma damage and native oxide layer. The Schottky barriers were also employed for DLTS, using a Fourier Transform (FT 1020) digital system.

Results and Discussion

Doping profiles for the Cz samples with and without plasma hydrogenation were obtained. Figure 1 shows the electron concentration at a depth of 1 µm. A first observation is that there could be some evidence for dopant passivation (or de-activation) for the H-plasma only samples, showing a 10 to 20 % lower doping concentration after 120 min hydrogenation. It is clear, on the other hand, that the TD anneal creates a strong increase of the electron concentration, which amounts to a factor 10 for the 50 h maximum anneal time, one can note that the rate of donor formation is higher in the plasma treated samples. For the longest anneals studied, the two processes, (i.e. with and without plasma) tend to the same carrier concentration profile, although a slightly higher value may still be achieved with hydrogenation.

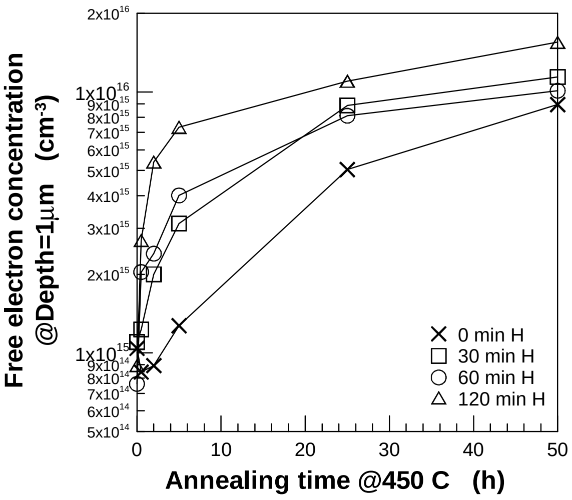

Figure 1: Carrier concentration level (at a depth of 1 µm) as a function of annealing time for hydrogenated (30 min, 1 h and 2 h) and non-hydrogenated Cz material.

In order to study the microscopic nature of the induced TDs, DLTS has been performed. Only a single peak with a large electron capture cross section (3 to $10x10^{-12}$ cm^2) and an activation energy of E_c-0.12 eV is observed. This could possibly be the double donor level of the oxygen thermal donors (4), although its position is unusually low. In addition, there is no trace of the single donor, which is possibly also shifted to lower energies. However, the biggest problem is that the trap concentration, in the range of $8{\cdot}10^{13}$ to $8{\cdot}10^{14}$ cm^{-3}, is more than one order of magnitude lower than the carrier increase derived from C-V measurements. This points to the creation of a large concentration of unknown shallow donors, which are not accessible by DLTS. A similar conclusion has recently been reached for the TD formed in oxygenated Float-Zone (FZ) silicon (5). For the moment, DLTS analysis of the annealed samples without plasma is underway to verify the presence of OTDs.

Conclusion

It has been shown that the use of plasma hydrogenation enhances the introduction rate of TDs in 450°C-annealed n-type Cz silicon. However, it is strongly believed that in the hydrogenated samples, ultra-shallow donors, different from the OTDs are responsible for the donor increase.

References

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