Excimer laser annealing: a solution for the future technology nodes?

V. Privitera[*], G. Mannino[*], A. La Magna[*], G. Fortunato[**], L. Mariucci[**], B.G. Svensson[***]
[*]CNR-IMM, Catania, Italy
[**]CNR-IFN, Roma, Italy
[***]University of Oslo, Norway

Excimer laser annealing (ELA) of ion implanted Si [1] has recently received renewed interest within the semiconductor community for its possible application to the formation of ultra-shallow junctions in Si. The technique offers many advantages compared to rapid thermal annealing (RTA) procedures, such as control over the junction depth and a higher dopant activation efficiency. When irradiating Si with laser light at a sufficient energy density, a melted zone is formed in the material and a sharp transition between liquid and solid phase is formed [2]. The diffusivity of B is ~10^{-4} cm^2/s in the liquid Si, and the dopant is able to redistribute uniformly within the melted layer. Immediately after irradiation, the liquid-crystal interface advances towards the surface at a rate of ~ 5 m/s. As a result of such rapid solidification, less dopant is segregated into the liquid phase and enhanced dopant trapping occurs.

The results presented are relative to the redistribution and electrical activation of Boron implanted in Si with energy of 1keV and doses between 1×10^{14} and 5×10^{15} $ions/cm^2$. Post-implantation laser annealing was performed using a XeCl excimer laser (λ=308 nm, 28 ns pulse duration), equipped with a beam homogeniser, which formed a uniform 7x7 mm^2 spot on the sample. The dopant activation as a function of depth was measured by Spreading Resistance Profiling (SRP), whereas Secondary Ion Mass Spectrometry (SIMS) was used in order to obtain the chemical atomic concentration formed in the solid after ELA. An example of the carrier and chemical profiles that can be achieved by the ELA treatment is shown in Fig.1. Transmission Electron Microscopy was also performed upon as-implanted and ELA treated samples, enabling lattice imaging.

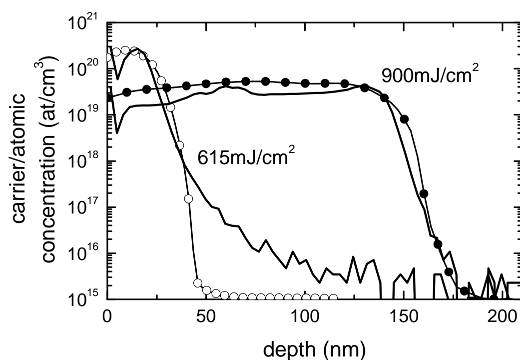

Fig.1 SRP (symbols) and SIMS (lines) profiles of a 1 keV B, $1\times10^{15}/cm^2$ implant treated by ELA for two different energy densities.

In order to explain the dopant behaviour during melting and regrowth, a model considering the melt depth, melt time and interface velocity, has been developed. The model considers standard diffusion equations with diffusivity coefficients D_l, D_s and D_{ox} in the liquid Si, solid Si and solid SiO_2 material respectively. During the ELA process the dopant density C evolves according to the equation:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left(D(z) \frac{\partial C}{\partial z} \right) \qquad (1)$$

where

$$D(z) = \begin{cases} D_{ox} & if\ z_{surf} < z < z_{ox} \\ D_l & if\ z_{ox} < z < z_{\text{int}} \\ D_s & if\ z > z_{\text{int}} \end{cases} \qquad (2)$$

and z_{surf} , z_{ox} and z_{int} are the free surface, SiO_2-Si interface and liquid-solid interface positions respectively. Note that z_{surf} , z_{ox} are fixed, whilst we assume an ideal motion of z_{int} with constant speeds during melting and regrowth (estimated from thermal simulations), a smooth inversion of the motion in the region where the maximum melt depth is reached and a smooth deceleration when approaching the surface. At high implantation doses, the dopant atomic density may approach the thermodynamic limit. This effect has been incorporated into the model and a reduced value of the segregation coefficient is considered, when the dopant incorporation process becomes restricted with respect to the case for lower doses.. As the simulation results suggest in Fig. 2, the dopant profile formed in Si after ELA, below the thermodynamic limit, is an intrinsic property of the process, and is governed by the diffusion equation.

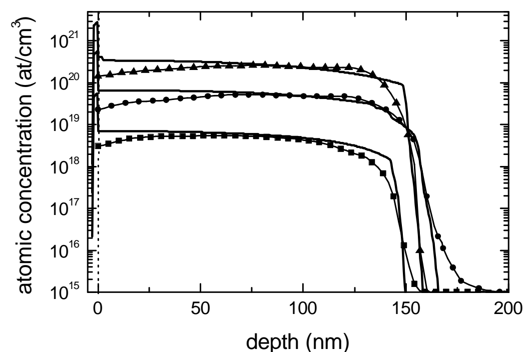

Fig.2 SRP (symbols) and Simulations (lines) profiles of 1 keV B, 1×10^{14}, 1×10^{15} and $5\times10^{15}/cm^2$, after ELA at 900 mJ/cm^2.

The results show that ultra-shallow (<100nm), electrically active B profiles can be successfully formed in Si following ULE ion implantation and ELA. A fraction of the implanted dopant is lost from the sample during laser annealing through redistribution into the surface region. The dopant retained in the solid is fully activated, and the material formed after liquid phase epitaxial re-growth is highly crystalline. At an atomic concentration below the thermodynamic limit, the activation efficiency is a constant irrespective of dose implanted for a fixed melt depth.

Acknowledgements

The authors gratefully thank Sean Whelan for his outstanding work on this activity made at CNR-IMM, Applied Materials (UK) for the implants, Markus Italia for the SRP measurements, Patrick Leveque and J.S. Christensen for the SIMS analysis. The research has been partially funded by the EU projects ENDEASD (FMRX-CT98-0208) and FLASH (IST-2001-38901).

References

[1] R. F. Wood, J. R. Kirkpatrick and G. E. Giles, Phys. Rev. B 23, 5555 (1981).
[2] E. Rimini, in "Surface modification and alloying by laser, ion and electron beams", edited by J. M. Poate, G. Foti and D. Jacobsen, chapter 2 p.26, (Plenum press, New York 1983).