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Mechanisms of Laser Annealing

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Since the pioneering Russian studies[1] of laser annealing, there has been much activity centered on understanding the phenomena and investigating potential semiconductor applications.[2] In this paper we review the mechanisms with respect to the annealing of ion implantation damage, regrowth of deposited Si layers and reaction of metal films with semiconductors. At present two distinct regimes have been established. In the pulsed or high-power laser mode melting occurs and in the CW or low power mode regrowth or atomic motion occur in the solid phase. Although the annealing or regrowth processes appear to be caused simply by heating, the spatial and temporal localization afforded by the laser permits the fabrication of alloys or structure that are inaccessible to other techniques.

The first experiments to demonstrate the melting regime were those involving Q-switched Nd:YAG or Ruby irradiation of implanted Si. We will illustrate this from our own experiments[3] using finely focused Nd:YAG irradiation, typically 100 nsec pulses, where the 40 μm beam spots were moved in 10 μm steps to generate large irradiated areas. Silicon was amorphized with implants of As or other dopants and then irradiated with the laser. Above the laser energy threshold the amorphous layer recrystallized to perfect single crystal Si and the As was completely incorporated on lattice sites. The As, however, had diffused considerable distances and such motion could only be explained by diffusion in the liquid phase. Moreover surface morphology was observed consistent with melting. The melting mode was unambiguously established by Auston et al.[4] who measured the reflectivity of the Si during irradiation. Abrupt increases in reflectivity were observed due to the metallic nature of liquid silicon.

Cooling rates in the melting regime are $\sim 10^9$ °K/sec and the formation of metastable phases should therefore be expected. Indeed many experiments have now demonstrated that the equilibrium solid solubilities of many common dopants in Si or GaAs can be enhanced by laser annealing.[2] We have examined the enhancement of Ga[5] and Pt[6] solubilities in Si following laser annealing in the liquid phase. Platinum solid solubilities can be enhanced by up to three orders of magnitude. The fact that these systems demonstrate retrograde solubility provides firm evidence for the occurrence of non-equilibrium impurity trapping processes at the solid-liquid interface during crystal growth.

The efficacy of CW laser irradiation for annealing implanted Si has been demonstrated by Gibbons and co-workers.[7] We have shown[8], by the use of high resolution Rutherford backscattering and channeling, that regrowth occurs in the solid phase without melting. As normal impurity diffusivities in Si are extremely low in the solid state compared to the liquid state (for example, $D_{As}(1100°C) = 2\times10^{-14}\ cm^2/sec$, some 10 orders of magnitude less than in the liquid), virtually no change in depth profiles is expected for CW irradiation. In fact, no motion of the dopants is observed in the solid phase regime.

It is of considerable importance to establish the behavior of deposited layers on Si under laser irradiation. We have demonstrated[5] that deposited Si layers on Si can be epitaxially regrown in both the liquid and solid phase regimes. To ensure epitaxial regrowth in the solid phase, the Si interface must be exceptionally clean. However in the liquid phase epitaxial regrowth has been achieved with some 15 Å of oxide at the silicon interface. We have also reacted[9] thin metal films of Ni, Pd and Pt with Si using pulsed Nd:YAG irradiation. Reaction occurs in the liquid phase and layers of considerable lateral uniformity can be produced.

References

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