Digest of Tech. Papers The 14th Conf. (1982 International) on Solid State Devices, Tokyo

A-6-2
(Invited)

LASER ANNEALING OF SEMICONDUCTORS*

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In the past few years many investigations have concentrated on the use of directed energy sources for processing semiconductors. Transient processing using optical sources or electron beams has the great advantage that the high temperatures during processing can be confined to the near-surface region, leaving the bulk unaffected by the processing step. These techniques also are naturally suited to localized annealing on a planar substrate. The early work in the area of transient processing concentrated on the use of scanned and pulsed sources for annealing ion implantation damage. Recently this area of research has expanded to include recrystallization of silicon on insulators, photochemical processing of semiconductors, surface cleaning and preparation, as well as many other directions of future interest to device technology. Excellent reviews of the remarkable progress made in the area of transient processing (fundamental mechanisms as well as applications) can be found in Refs. 1-4.

Pulsed laser or electron beam annealing of semiconductors has provided the opportunity to study unique regimes of high speed nonequilibrium crystal growth. Although the mechanism of pulsed laser annealing has been the subject of some controversy, it has now been established conclusively that annealing of ion implantation damage and dopant incorporation into electrically active substitutional lattice sites takes place by means of liquid phase epitaxial regrowth. In pulsed laser annealing, the absorbed laser light leads to melting of the near-surface region to a depth of several thousand angstroms. The melted region recrystallizes from the underlying substrate at growth velocities that are calculated and measured to be several meters/sec. At these very high growth velocities, recrystallization of the melted region takes place under conditions that are far from equilibrium at the moving liquid-solid interface. Results will be presented which demonstrate that substitutional impurities can be incorporated into the silicon lattice at concentrations that greatly exceed equilibrium solubility limits. Values for the (nonequilibrium) interfacial distribution coefficient from the liquid (k') are found to be much greater than corresponding equilibrium values (k_o). Values determined for k' are functions of both growth velocity and crystal orientation. For each substitutional impurity there is a maximum concentration (C_s^{max}) which can be incorporated into the lattice. Measured values for C_s^{max} are functions of growth velocity and are approaching predicted limits to solute trapping in silicon. Mechanisms limiting substitutional solubilities have been identified. Results on the thermal stability of these supersaturated alloys will be presented.

The behavior of nonsubstitutional impurities in silicon during pulsed laser annealing is quite different from that of Group III or V dopants. For the nonsubstitutional impurities, pulsed laser annealing causes complete segregation of the impurity to the surface. These results suggest that the impurity diffusivity in the interfacial region is the important parameter in determining whether a given impurity will be trapped or zone refined during pulsed laser processing. The results suggest that pulsed laser annealing can be used as an efficient method to zone refine these impurities from a depth equivalent to the maximum melt front penetration.

Transient thermal processing using pulsed or cw lasers and electron beams as well as incoherent optical sources is now being extensively investigated in areas of direct interest to device technology. These areas include (but are by no means limited to) fabrication of abrupt junctions and buried, doped layers in silicon, recrystallization of silicon films on insulators, and electrical activation of implanted dopants in polycrystalline material. Selected examples from several of these areas will be presented.

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*Research sponsored by the Division of Materials Sciences, U. S. Department of Energy under contract W-7405-eng-26 with Union Carbide Corporation.

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