GALLIUM DISTRIBUTION AND ELECTRICAL ACTIVATION
IN Ga+-IMPLANTED Si

M. Y. Tsai and B. G. Streetman

Coordinated Science Laboratory and
Department of Electrical Engineering
University of Illinois at Urbana-Champaign
Urbana, Illinois 61801

V. R. Deline and C. A. Evans, Jr.

Department of Chemistry and
Materials Research Laboratory
University of Illinois at Urbana-Champaign
Urbana, Illinois 61801

(Received August 10, 1978; revised November 24, 1978)

Gallium distribution profiles in Ga+-implanted silicon have been measured by secondary ion mass spectrometry (SIMS) and differential Hall effect methods. The previously reported penetrating tails are not observed for as-implanted samples. The redistribution of Ga during annealing is affected by ion damage and effects due to recrystallization of the amorphous layer. Electrical carrier profiles indicate that carrier concentration higher than the usual Ga solid solubility can be achieved in Ga-implanted Si recrystallized at 600°C. However, this large acceptor concentration diminishes after higher temperature annealing. For 900°C anneals, the carrier concentration is limited by the Ga solid solubility and some compensation due to unannealed ion damage.

Key words: ion implantation, doping, impurity profiles
Introduction

Although diffused gallium has been used successfully as an acceptor dopant in various silicon devices (1), its usefulness has been limited by its high diffusivity in \( \text{SiO}_2 \). This problem is avoided by using ion implantation, however, and gallium is now an attractive alternative to boron as a p-type dopant in a variety of Si devices. \( \text{Ga}^+ \)-implanted resistors (2,3) and \( \text{p}^+ \text{n} \) junctions (3,4) have previously been discussed; however, the understanding of \( \text{Ga}^+ \)-implanted Si is rather limited. Early studies have led to contradictions over the existence of a penetrating tail after implantation (5-7). Anomalous redistribution of Ga after annealing has also been observed (8). These results make the acceptor distribution in Ga-implanted Si difficult to predict. The electrical activation of Ga has been discussed briefly in several early papers (7,9-12), but carrier concentration profiles have not been studied in detail.

Since boron inside an implanted amorphous layer is fully activated by recrystallization at low temperature (\( \sim 550^\circ\text{C} \)) (7,13,14), it is interesting to know whether Ga can also be activated fully by recrystallization at these temperatures. The critical dose of \( \text{Ga}^+ \) to form an amorphous Si layer at room temperature is \( \sim 2.5 \times 10^{14} \text{ cm}^{-2} \) (15), which is much lower than for \( \text{B}^+ \) implants (\( > 2 \times 10^{16} \text{ cm}^{-2} \)) (16). Hence, \( \text{Ga}^+ \) implantation can result in an amorphous Si layer at room temperature with practical doses. No additional amorphizing \( \text{F}^+ \) or \( \text{Si}^+ \) implants are necessary, as in the case of \( \text{B}^+ \)-implanted Si (13,14). In this respect, \( \text{Ga}^+ \) implantation of Si is superior to \( \text{B}^+ \) implants when amorphization is required.

In this work, we have studied atomic Ga distributions by secondary ion mass spectrometry (SIMS) for as-implanted and annealed samples. We find no pronounced tail in as-implanted samples for Ga\(^+\) fluences either below (\( 1 \times 10^{14} \text{ cm}^{-2} \)) or above (\( 1 \times 10^{15} \text{ cm}^{-2} \)) the critical fluence for amorphization. By comparing electrical carrier profiles with the SIMS atomic profiles, we find that redistribution and electrical activation of implanted Ga is affected by recrystallization, solid solubility, and ion damage.