

Physics of Semiconductor Devices

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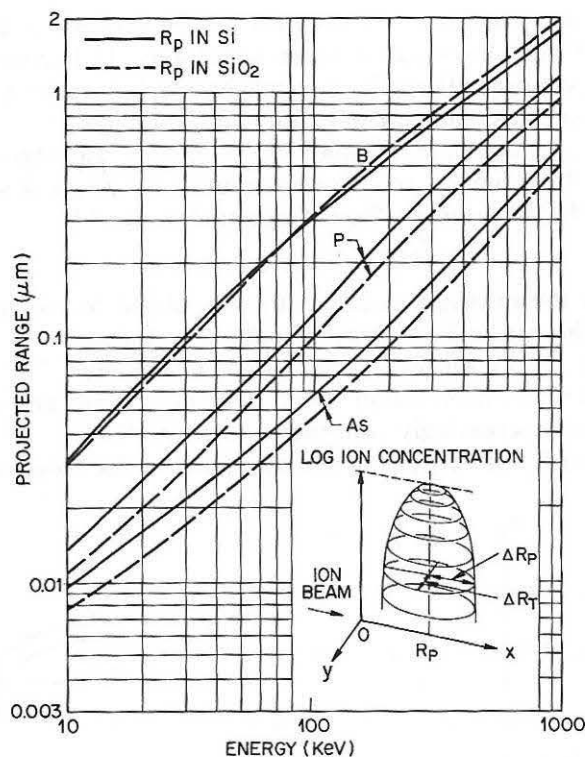


Fig. 6 Projected range of boron, phosphorus, and arsenic ions in Si and SiO₂ as a function of implantation energy. The insert shows the distribution of the implanted ions. (After Pickar, Ref. 10.)

impurity, which is the maximum concentration of an impurity that can be accommodated in a solid at any given temperature. The solid solubilities of some important impurities in Si are plotted in Fig. 5 as a function of temperature.²¹ This figure shows that arsenic or phosphorus should be used as the impurity in making heavily doped *n*-type silicon, and boron should be used for heavily doped *p*-type silicon.

Ion implantation is the introduction of energetic charged atomic particles into a substrate for the purpose of changing the electrical, metallurgical, or chemical properties of the substrate. The typical ion energies considered are between 10 and 400 keV, and typical ion doses vary from 10^{11} to 10^{16} ions/cm². The main advantages of ion implantation include (1) precise control over total dose, depth profile, and area uniformity; (2) low-temperature processing; and (3) implanted junctions that can be self-aligned to the edge of the mask.

For an ion beam with an infinitesimally small beam diameter, the ion distribution in the substrate (Fig. 6, insert) is given by¹⁰

$$n(x, y) = \frac{s}{(2\pi)^{3/2} \Delta R_p \Delta R_t^2} \exp\left[-\left(\frac{x - R_p}{\sqrt{2}\Delta R_p}\right)^2\right] \exp\left[-\left(\frac{y}{\sqrt{2}\Delta R_t}\right)^2\right] \quad (4)$$

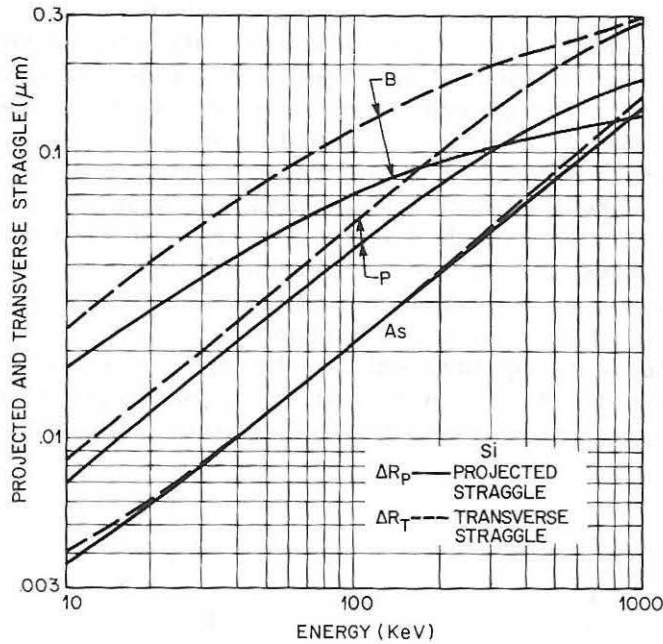


Fig. 7 Projected straggle and transverse straggle of boron, phosphorus, and arsenic in silicon as a function of implantation energy. (After Pickar, Ref. 10.)

where s is the incident rate of ions per second, R_p the projected range, ΔR_p the projected straggle, and ΔR_T the transverse straggle. Figure 6 shows values of R_p in Si and SiO_2 for boron, phosphorus, and arsenic ions as a function of implantation energy. The projected range increases approximately linearly with the energy. For boron, the projected ranges in Si and SiO_2 are quite close; however, for phosphorus and arsenic, the projected range in SiO_2 is about 20% lower than that in Si. The projected straggle and transverse straggle in Si for these ions are shown in Fig. 7. The straggles also increase with increasing energy. The ratio of ΔR_p to R_p over the energy range is about 0.2 to 0.5.

For an implantation from an infinitesimal beam that is scanned uniformly across the substrate surface, the y dependence of the doping density drops out in regions several ΔR_T from the edge of the scanned area. The doping distribution then becomes

$$n(x) = \frac{\phi}{\sqrt{2\pi}\Delta R_p} \exp\left[-\left(\frac{x - R_p}{\sqrt{2}\Delta R_p}\right)^2\right] \quad (4a)$$

which describes the Gaussian distribution in doping density of the implanted ions, where ϕ is the total number of ions per unit area, and the quantity $\phi/(\sqrt{2\pi}\Delta R_p)$ is the peak doping concentration at $x = R_p$.

Since 1974, laser processing of semiconductors has been extensively studied.^{22,23} High-intensity laser radiations [such as the pulsed ruby laser