Ion implantation

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Ion implantation is a technique for direct deposition of dopants into a crystal where a doping gas (eg. BF_3) is ionized, extracted and impacted into the target crystal.

Predeposition diffusion has a number of deficiencies. For example, *it is very difficult to accurately control the doping profile and region*, *doping by diffusion has to be performed at high temperatures meaning that other, unintentional diffusion in the crystal occurs as well*, *the crystal can easily be contaminated with other gases in the furnace while perfoming diffusion* and *it can be very challenging to create lightly doped regions which are important for MOSFETs for example (channels)*.

Ion implantation tackles these problems. *It allows to precisely measure and control the doping concentration and profile*, *avoids contamination by filtering the dopand gas through mass separation*, and *can be performed at room temperature thus avoiding unintentional diffusion*.

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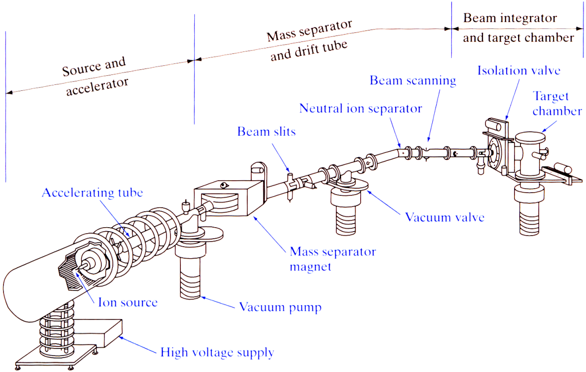
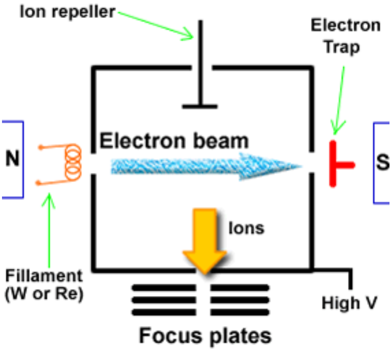
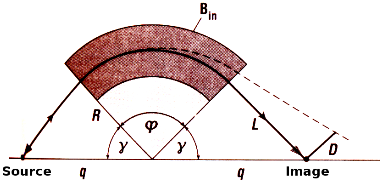


Source: Streetman, Ben G.; Banerjee, Sanjay - *Solid State Electronic Devices*



Source: `http://www.hull.ac.uk/chemistry/masspec3/principles%20of%20ms.html`



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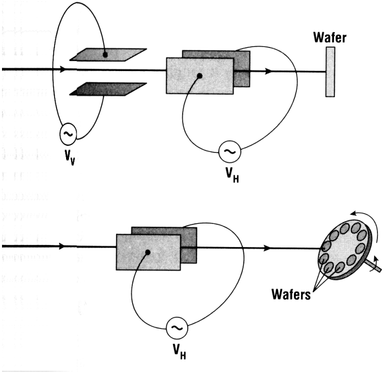
$$\frac{Mv^2}{r} = qvB \text{ and } v = \sqrt{\frac{2E}{M}} = \sqrt{\frac{2qV_{ext}}{M}}$$

thus

$$r = \frac{1}{B}\sqrt{\frac{2MV_{ext}}{q}}$$



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Deflection determines position of ion beam on target surface. Allows very precise and controlled scanning over the surface which guarantees highly customizable and reproducible doping patterns eligible for mass production.

Doping profile is approximately given by a Gaussian

$$N(x) = \frac{\Phi}{\sqrt{2\pi}\Delta R_p} \exp^{-\frac{1}{2}\left(\frac{x-R_p}{\Delta R_p}\right)}$$

- R_p: projected range
- ΔR_p: straggle
- Φ: dose (in cm^{-2}

Both R_p and ΔR_p increase with increasing beam energy. The dose is obtained by integrating the ion current over time.

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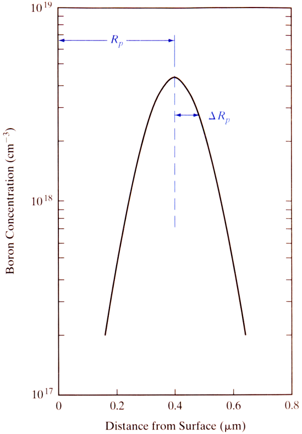
Typical Gaussian with the characteristic parameters R_P and ΔR_P



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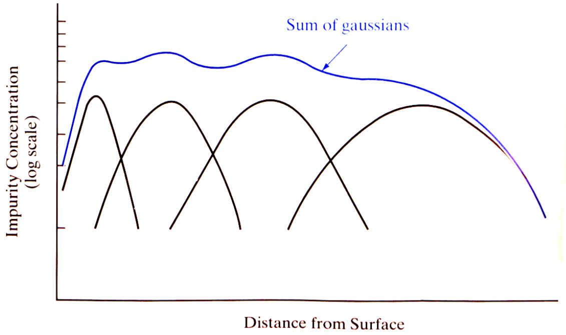
Custom doping profiles are obtained through subsequent implantations



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Right after implantation, only about 5 % of the dopants have been bonded to the crystal and are electrically active. It is therefore necessary to *activate* the implanted dopants through heat treatment. Due to the activation, diffusion will occur and the doping profile changes accordingly.

$$N(x) = \frac{\Phi}{\sqrt{2\pi}\sqrt{(\Delta R_p^2 + 2Dt)}} \exp^{-\frac{1}{2}\left(\frac{x - R_p}{\Delta R_p^2 + 2Dt}\right)}$$

- D: diffusivity
- t: time

Thus, to avoid strong unintentional diffusion, activation time must be kept as short as possible. One may use *rapid thermal annealing* (RTA) for activation.

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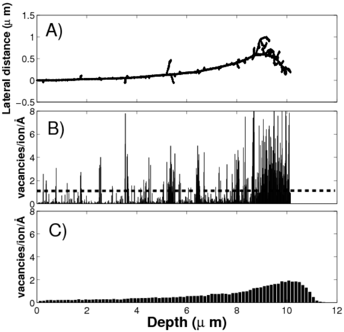
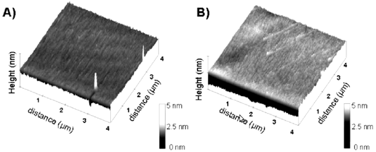


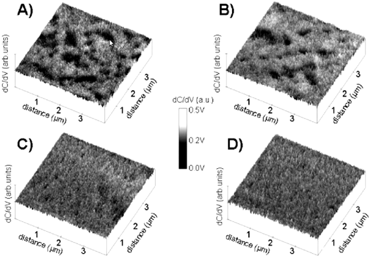
Source: L. Vines, E. V. Monakhov, J. Jensen, A. Yu. Kuznetsov, and B. G. Svensson. *Effect of spatial defect distribution on the electrical behavior of prominent vacancy point defects in swift-ion implanted Si.* Phys. Rev. B, 79(7):075206, February 2009

Topography scan (A) of the Si sample implanted with 3 MeV Au^{2+} ions with dose $5 \times 10^9 cm^{-2}$ from compared with a reference sample (B); there are no visible changes in the topography of the scan in (A) after ion bombardment. The electronic changes are only visible in the SCM images



Source: [2] Lasse Vines, Edouard Monakhov, Bengt G. Svensson, Jens Jensen, Anders Hallen, and Andrej Yu. Kuznetsov. *Visualization of MeV ion impacts in Si using scanning capacitance microscopy.* Phys. Rev. B, 73(8):085312, February 2006.

SCM images of Si samples implanted with 3 MeV Au^{2+} ions with dose $5 \times 10^9 \text{cm}^{-2}$ (A), $8 \times 10^8 \text{cm}^{-2}$ (B) and $2 \times 10^8 \text{cm}^{-2}$ (C), as well as an unimplanted sample (D). These images show dose-dependent changes in the electronic structure of the Si bulk which are not visible in topography scans using AFM.



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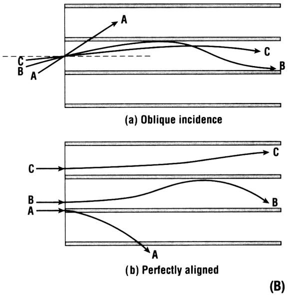
If ions move parallel to a major crystal direction, they can travel very long distance without any considerable energy loss due to scattering. This is called *channeling* and will disturb the doping profile.



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Critical angle: $\Psi = 9.73^{\circ}\sqrt{\frac{Z_i Z_t}{E_{inc} d}}$

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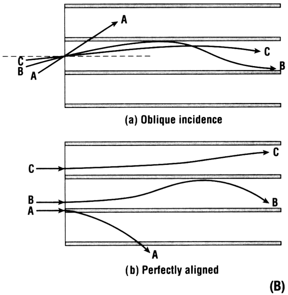

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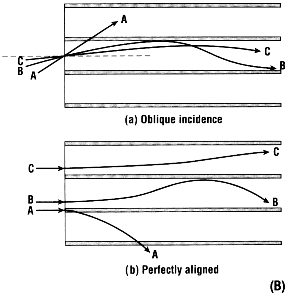

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- *Halbleitertechnologie von A bis Z* - `http://www.halbleiter.org`
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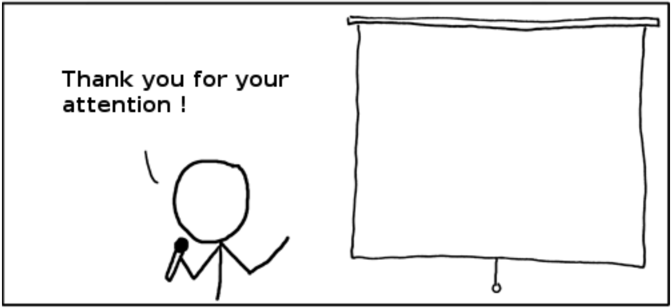
Thank you for your attention !