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What can we learn from photoluminescence studies of ion implantation damage in silicon

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Work carried out in collaboration with…

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Currently …

- Low damage reactions well known (see paper by Mika Huhtinen)
- E.g. vacancy V trapped by oxygen to give VO (‘A’ centre).
- Time to revisit problem of pure silicon.
- E.g. when [V] >> [dopants].
- Use ion implants, 4 to 5.6 MeV Si^+ into Si.

- Ion implantation modelling of Cowern et al Phys. Rev. Lett. **82** (1999) 4460 predicts stable small clusters of interstitials of 4 to 8 atoms.
- They are relevant to radiation damage studies.
- What are their properties?
- Need methods of studying *small*clusters.

Techniques

- DLTS : accurate concentrations if the defects are below the dopant level.
- Positron annihilation : probes vacancy clusters, can be quantitative.
- Photoluminescence : accurate energies, but is it quantitative?

Photoluminescence

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- Excite samples with low power visible laser
- Excitation energy absorbed in 1 μm
- Creates excitons which diffuse to defects…
- …and are trapped at them.
- Photon emitted by exciton decay has energy characteristic of the trap.
- Linewidths 10^{-4} of their energy.
- See J Appl Phys **88** (2000) 2309

Quantitative?

- Photoluminescence is not usually quantitative because of competing traps for excitation energy.
- But ratio of PL signal from a defect to that of a fixed concentration of defects can give quantitative data.
- E.g. concentration of ‘X’ (1049 meV) relative to shallow dopants is proportional to ion dose to power 0.8 over 4 orders of magnitude.
- See also recent DLTS data of Libertino et al, Phys Rev B **63** (2001) 195206.

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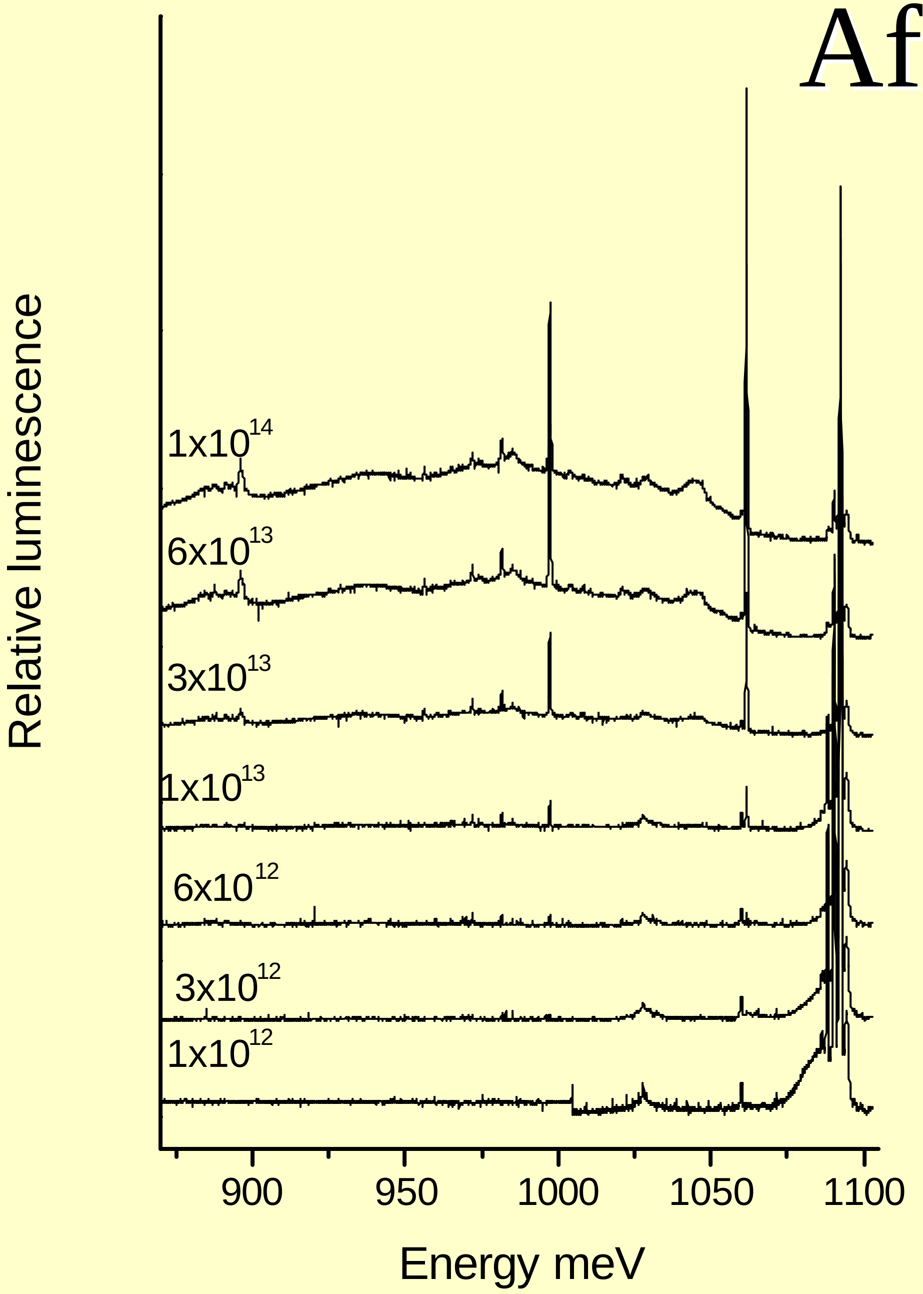
After R.T. implantation and no annealing…

- Positron annihilation data shows divacancy concentration proportional to dose to power 0.8 in top 0.8 μm of sample.
- Relative to TRIM, only a few percent of divacancies have survived immediate recombination.
- What happens on annealing?

After 600 C anneal
30 mins



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At this stage…

- Annealing at ~ 600 C cleans the damage for low implant doses (< ~10^{13} cm^{-2}).
- Damage persists for larger doses …
- … but PL intensity is large.

- Damage aggregates into vacancy-rich and interstitial-rich regions …

Energy confinement

- After annealing at 600 XC we find that for doses greater than 1013 cm-2, a vacancy-rich region forms at about 2 µm, and the interstitial layer is expected to be at 3 µm.
- Optical spectra show major changes for measurements at 7 to 40 K, but with constant total emission – energy is confined to the excited layer.
- See Davies et al, Nuc. Instr. & Methods (2001) in press.

Summary

- Defect survival at R.T is ~ few % of initial displacements.
- Common power law, defects prop. to dose$^{0.8}$ applies over 10^9 to ~10^{14} cm^{-2} !

Formation by 600 C of carrier confinement in vacancy-rich and interstitial-rich layers.

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