MOVING INTRINSIC LOCALIZED MODES IN GERMANIUM PRODUCED BY A LOW ENERGY PLASMA

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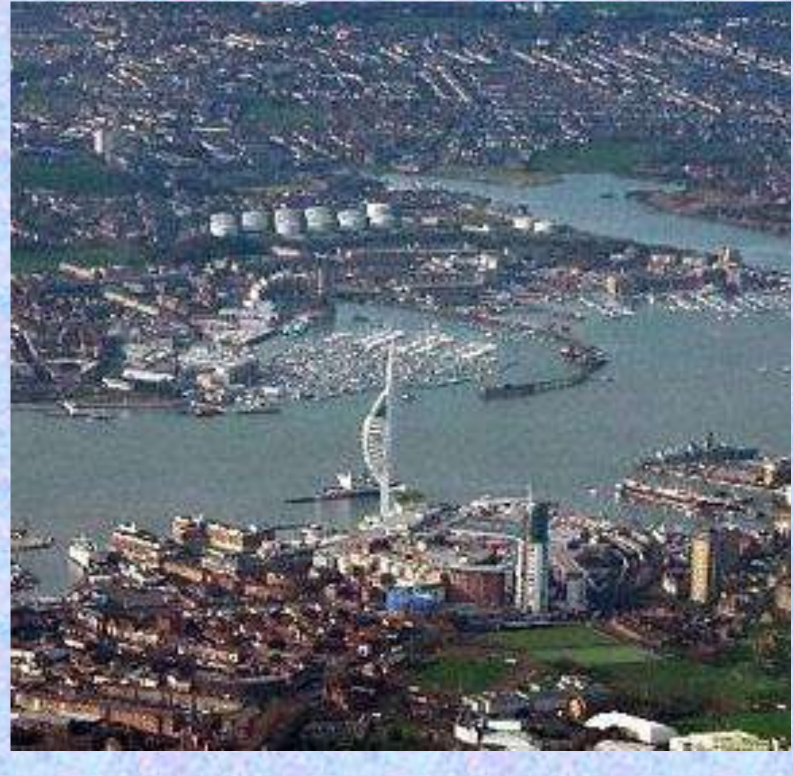

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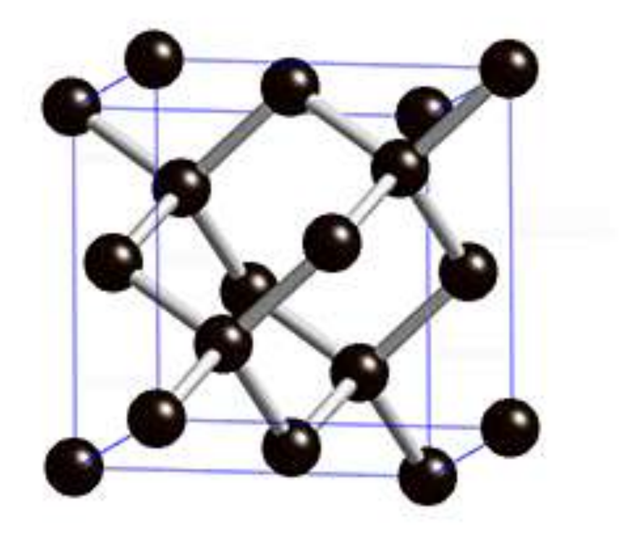
Outline

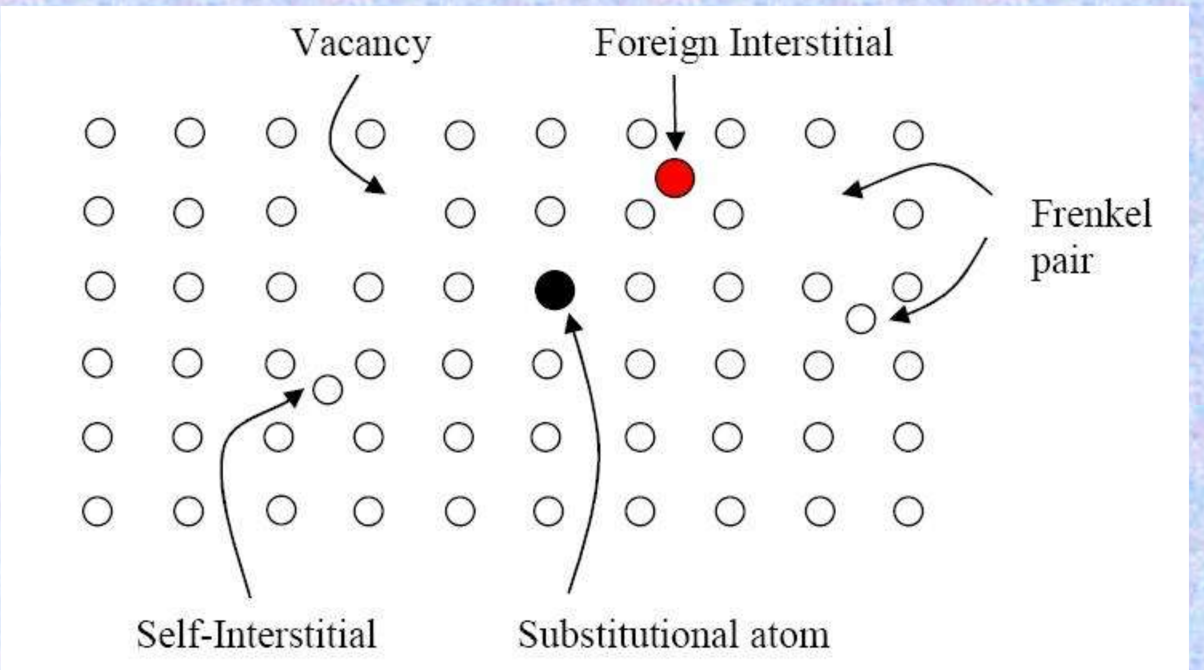


We believe that there are moving intrinsic localized modes (ILMs) in germanium

- The defect E center
- The plasma source
- The annealing of defects with a plasma
- Comparison with phonons
- Characteristics of ILMs in Ge that we can estimate

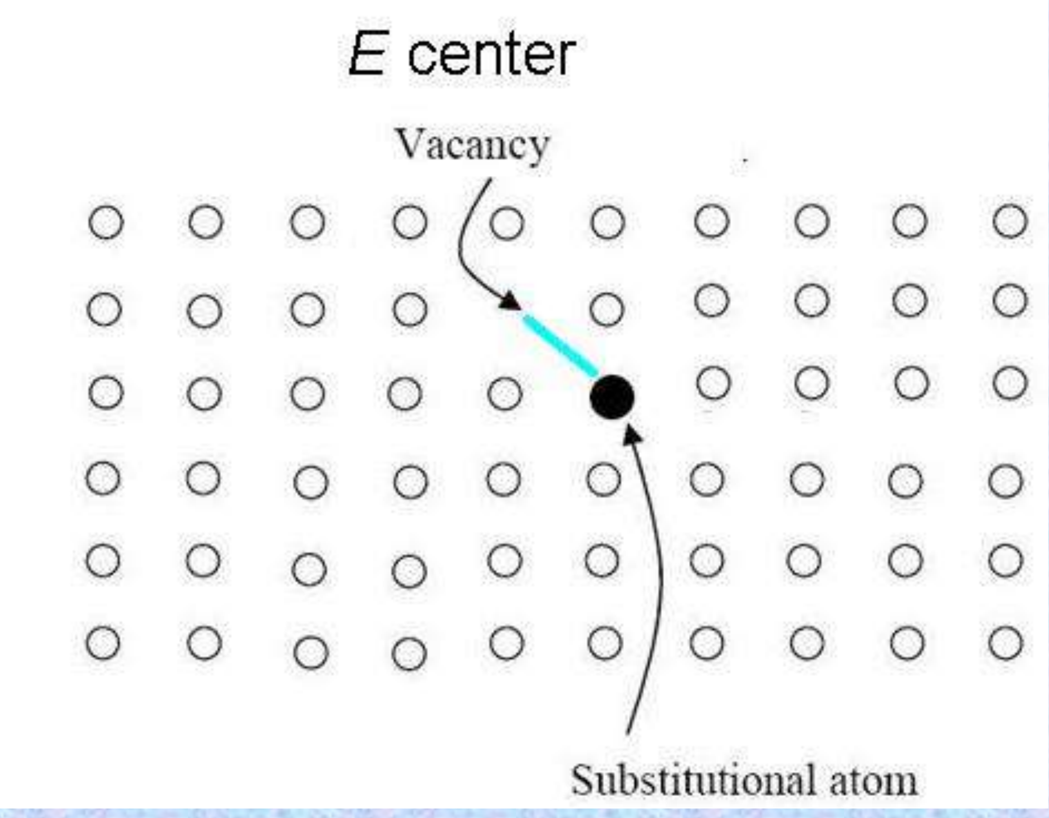
Defects in germanium

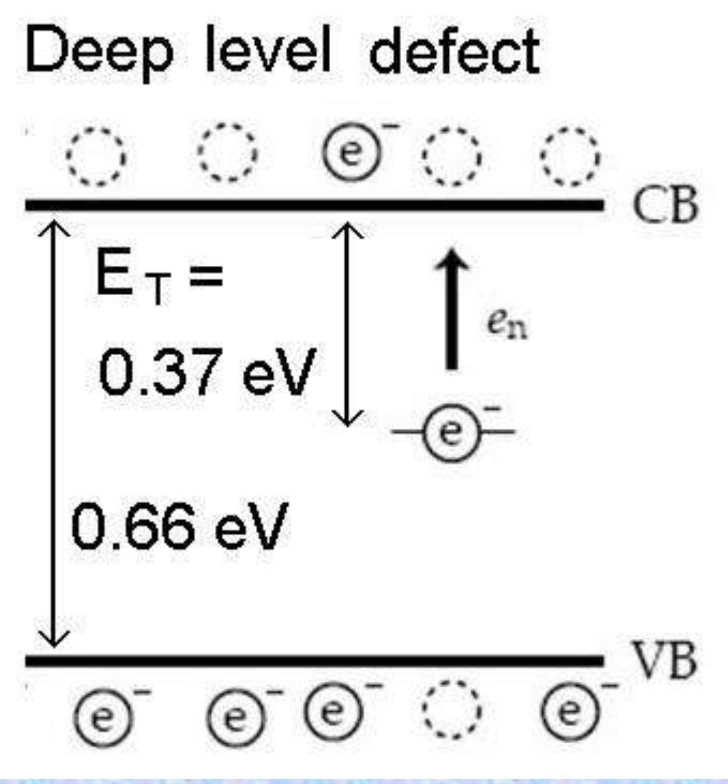
- Can be produced by irradiation as 5 Mev alpha particles
- Some are unconvenient but some are of technological interest



The defects *E* center in germanium

- *E* center : vacancy bound to a substitutional Sb
- *E* center is an electron trap

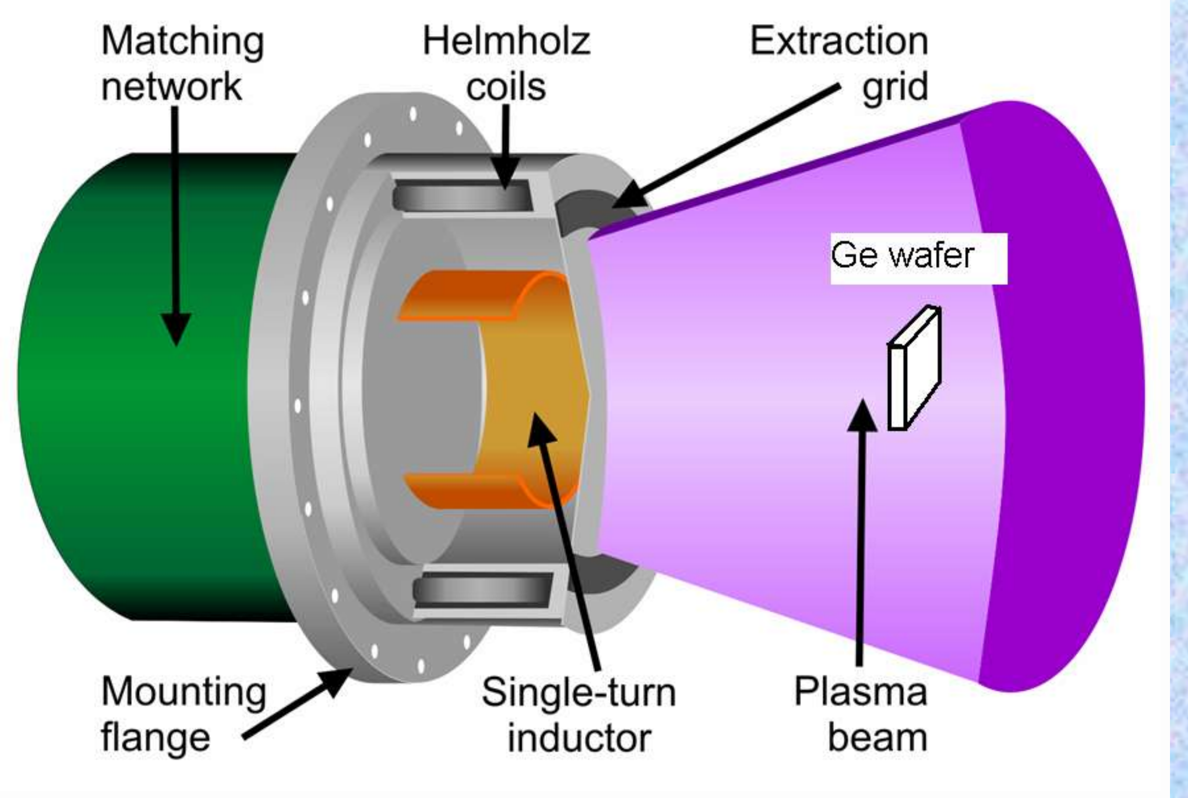




$$e_n = \gamma_n T^2 \exp(-\frac{E_T}{kT})$$

Plasma source COPRA DN-160

- Inductively coupled (ICP)
- It can have low flux and low energy
- Ions impact almost perpendicular to the wafer



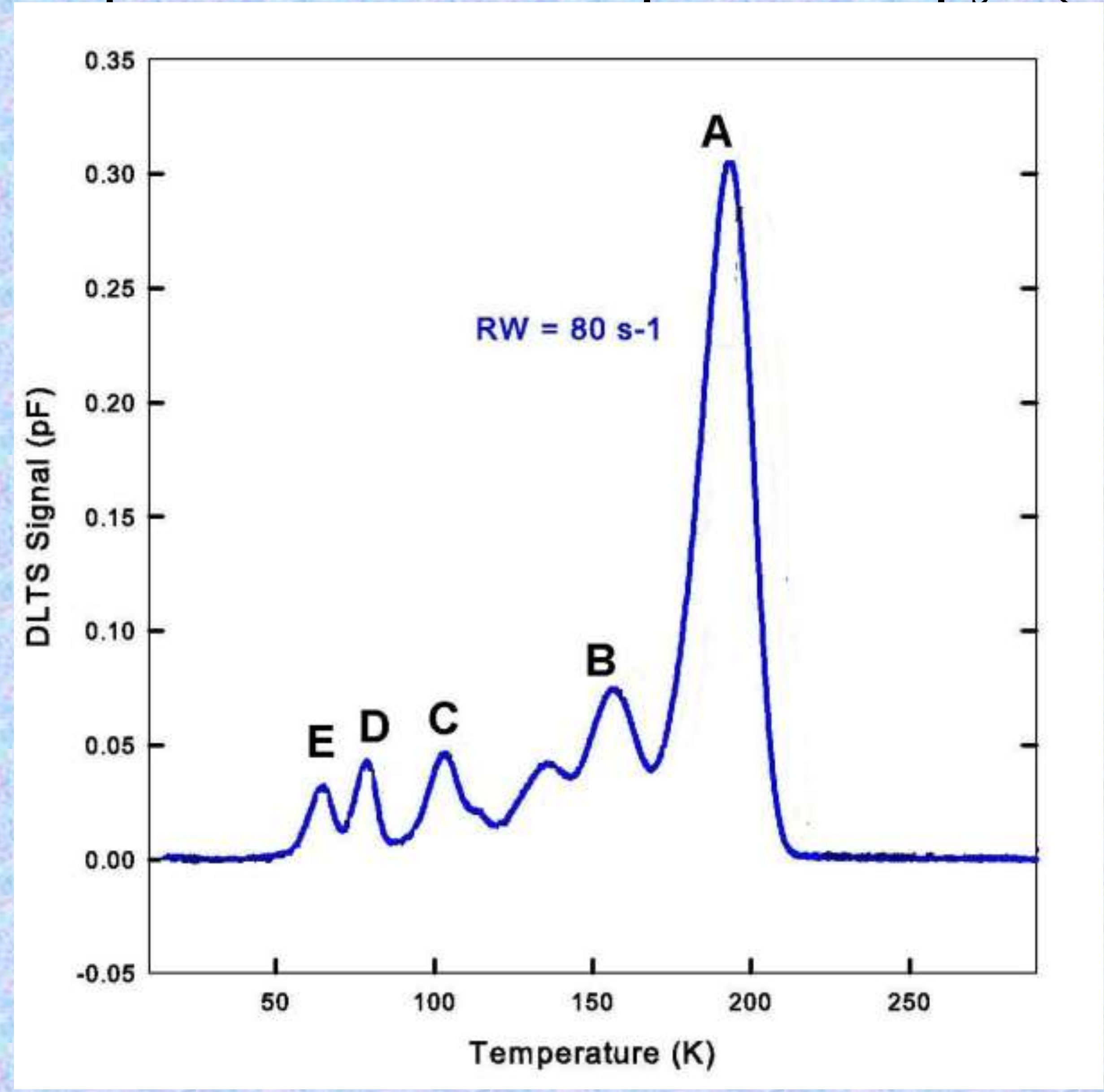
•Our experiment:

High pressure:
$p=0.1$ mb

Very low flux:
$\Phi=5.6\text{x}10^{10}\ \text{cm}^{-2}\text{s}^{-1}$

Low ion energy
$K=4$ eV

Deep level transient spectroscopy (DLTS): Example



Defect A:

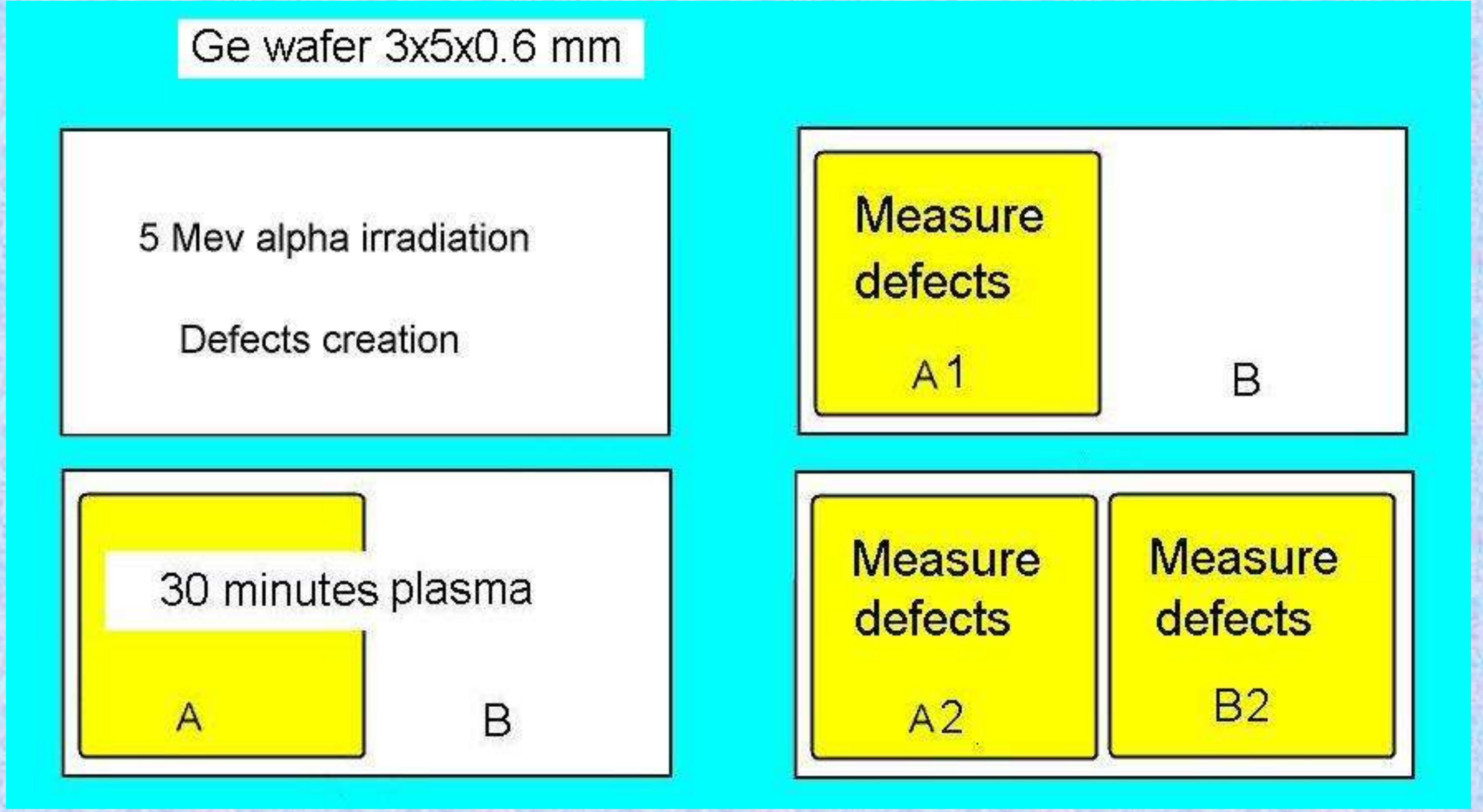
$$RW_1 = 80s^{-1} = e_n(T_A)$$

Defect B:

$$RW_1 = 80s^{-1} = e_n(T_B)$$

Defect C …..

Our basic experiment: 4 eV ICP plasma annealing



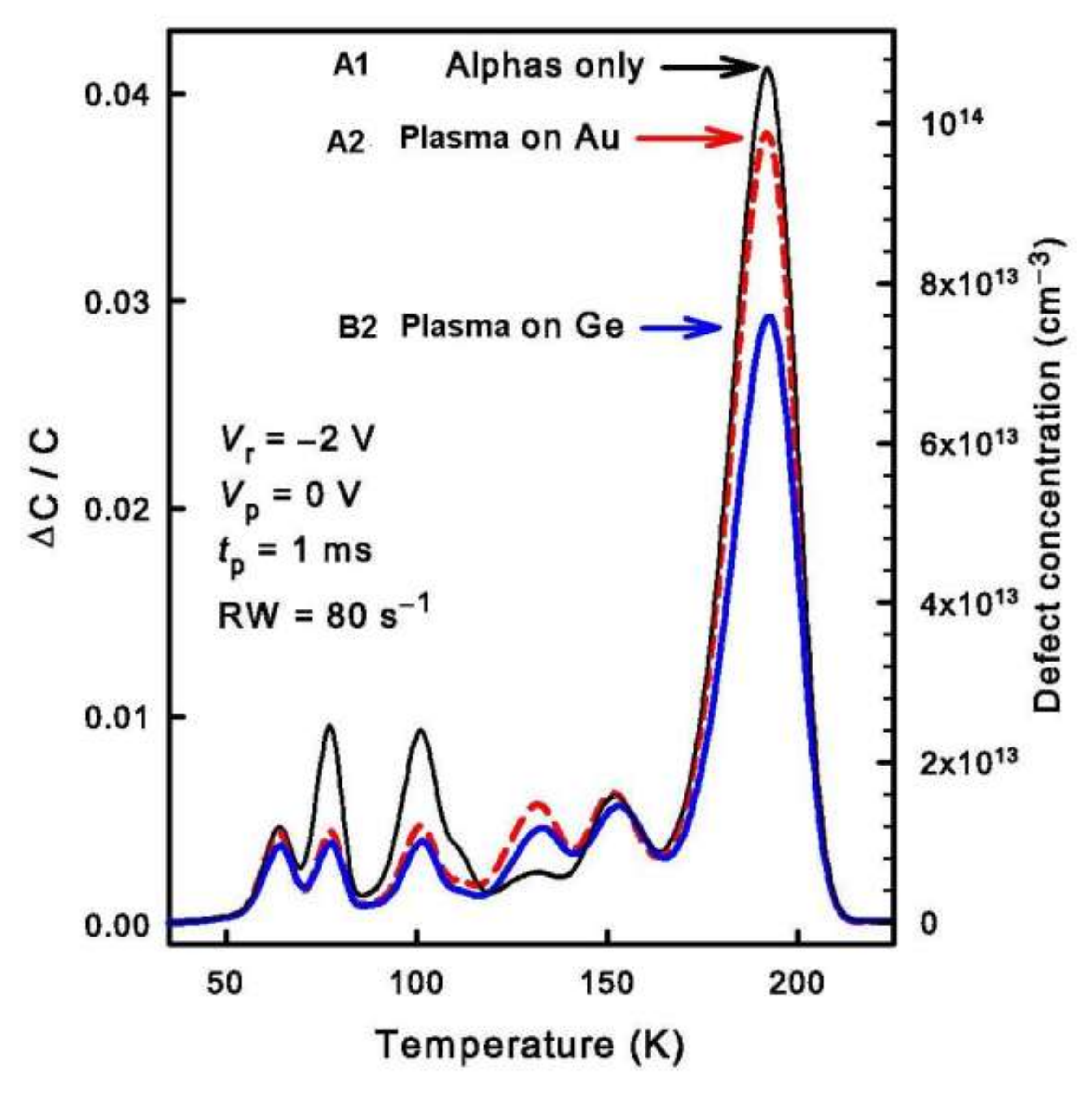
Ge wafer 3x5x0.6 mm

5 Mev alpha irradiation

Defects creation

30 minutes plasma

Our basic experiment: 4 eV ICP plasma annealing



1.-Sb doped Ge is damage with 5 MeV alpha particles

2.- Rest 24 hours

3.-Au diode is evaporated in half the sample (half A)

4.- DLST in A
(black, alphas only)
5.-ICP in A and B

6.- Au diode in B

7.- DLTS in A (red-dashed)
(red, ICP on Au)

8.- DLTS in B
(blue, ICP on Ge)

Our basic experiment: Facts

1.-Sb concentration: $1.3\text{x}10^{15}$ cm^{-3} (n_i= $2.4\text{x}10^{13}$ cm^{-3}) ; 1 Sb per 10^8 Ge

2.- Metal (Au) thickness: 25nm

3.- After ICP on Ge the E center concentration drops 29% from N_T= $1.07\text{x}10^{14}$ cm^{-3}

4.- If ICP is done on Au, the E center reduction is smaller, but exists.

5.- ICP is done for 30 minutes in 10 minutes intervals to prevent heating

6.- Defect annealing occurs up to 2.600 microns or 4600 lattice units

7.- If the plasma ion energy is increased the effect is smaller

8.- Thermal annealing has to be done at 157 C to obtain a similar effect

Our hypothesis: Ar ions impacting on Ge produce ILMs, which travel through Ge and anneal the defects.
Why?

1.-ILMs with MD in metals by Hyzhnyakov group have 0.5-5 eV

2.-The maximum energy transfer from Ar to Ge is 3.6 eV

3.- The energy for annealing an E center is about 1.0 eV.

4- Therefore, the energy delivered by Ar atoms has to remain localized while traveling 10^4 lattice units

5.- Increasing the energy of the plasma does not enhance the effect, this is typical of ILM which often have a definite range or energies.

6.- At least stationary ILMs have obtained for Si and Ge with MD.

Some estimate numbers for ILMs

1.-Ion current can be measured, $\Phi_{\mathrm{Ar}} = 5.6\times 10^{10}\,\mathrm{cm}^{-2}\mathrm{s}^{-1} \approx 0.01\,\mathrm{ions}$ per squared lattice unit and minute

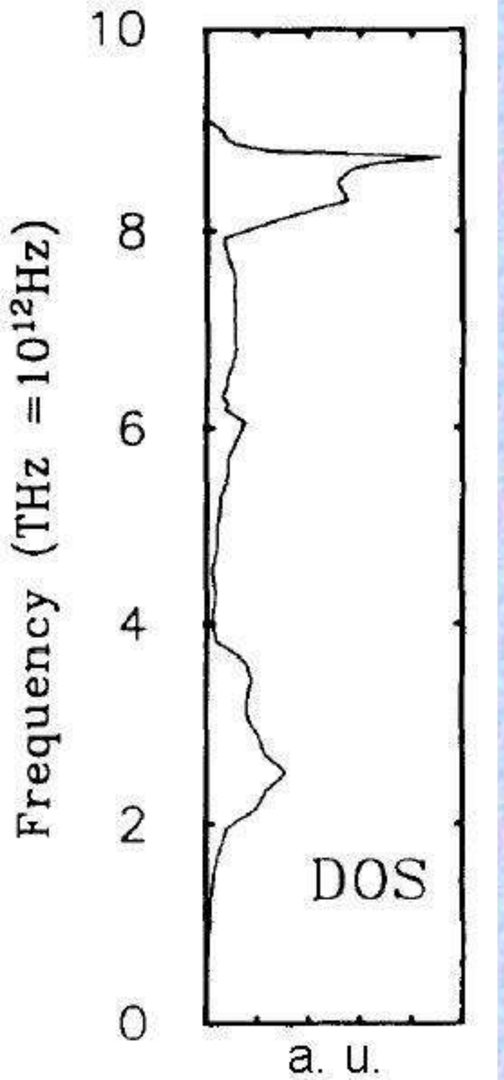
2.- ILM creation efficiency: γ : $\Phi_{\mathrm{ILM}} = \gamma\,\Phi_{\mathrm{Ar}}$; $\gamma < 1$

3.-Energy and velocity of ILMs $E_{\mathrm{ILM}} \approx 3\,\mathrm{eV}$; $c_s = 5400\,\mathrm{m/s}$

3.-Density of of IlMs: $n_{\mathrm{ILM}} = \dfrac{\Phi_{\mathrm{ILM}}}{c_s} \approx \gamma \times 2.3\times 10^{7}\,\mathrm{cm}^{-3}$

4.- Energy density for ILMs $\rho_{\mathrm{ILM}} = n_{\mathrm{ILM}} E_{\mathrm{ILM}} \approx \gamma \times 3\times 10^{5}\ \mathrm{eV/cm}^{3}$

Some estimate numbers for phonons at annealing temperature 157 C



1.-Phonon energy, Einstein model

$$E_{\mathrm{Ph}} \approx 8.5\,\mathrm{Thz} \approx 0.035\mathrm{eV}$$

2.-Number of phonons at annealing temperature T_{A}=157 C

$$n_{\mathrm{Ph}} = \frac{3n_{\mathrm{Ge}}}{\exp(E_{\mathrm{Ph}}/k_B T_A) - 1}$$

3.-Phonon energy density at T_{A}

$$\rho_{\mathrm{Ph}} = n_{\mathrm{Ph}} E_{\mathrm{Ph}}$$

4.- Ratio of energy densities for the same annealing rate

$$\boxed{\frac{\rho_{\mathrm{Ph}}}{\rho_{\mathrm{ILM}}} \approx 10^{-16}}$$

ILM-defect interaction cross-section and ILM creation efficiency

Minimal interacion cross-section $\sigma_0 = n_{\mathrm{Ge}}^{-2/3} \approx 10^{-15}\mathrm{cm}^2$

ILM-defect interaction cross-section $\sigma_{\mathrm{ILM}} = \alpha\,\sigma_0 \quad ; \quad \alpha > 1$

$$-\frac{1}{N_T}\frac{dN_T}{dt} = \sigma_{\mathrm{ILM}}\Phi_{\mathrm{ILM}} = \alpha\,\gamma\,\sigma_0\Phi_{\mathrm{Ar}}$$

$\alpha\,\gamma =$ (ILM creation efficiency) X (relative cross section)~ 3.6

Reasonable values: $\alpha \approx 6^2\sigma_0 \quad ; \quad \gamma \approx \dfrac{1}{10}$

Conclusions:

1.- Plasma ions of 4eV produces annealing of defects very deep in Ge

Likely conclusions:

2.- 4 eV Ar hits produce ILMs in Ge with very high efficiency

3.- ILMs of energy ~3eV travel distances of the order of at least 10^4 lattice units or 2.6 microns

4.- The annealing efficiency of ILMs with respect to phonons is extremely large

5.- Ar hits are very efficient at producing ILMs in Ge

References

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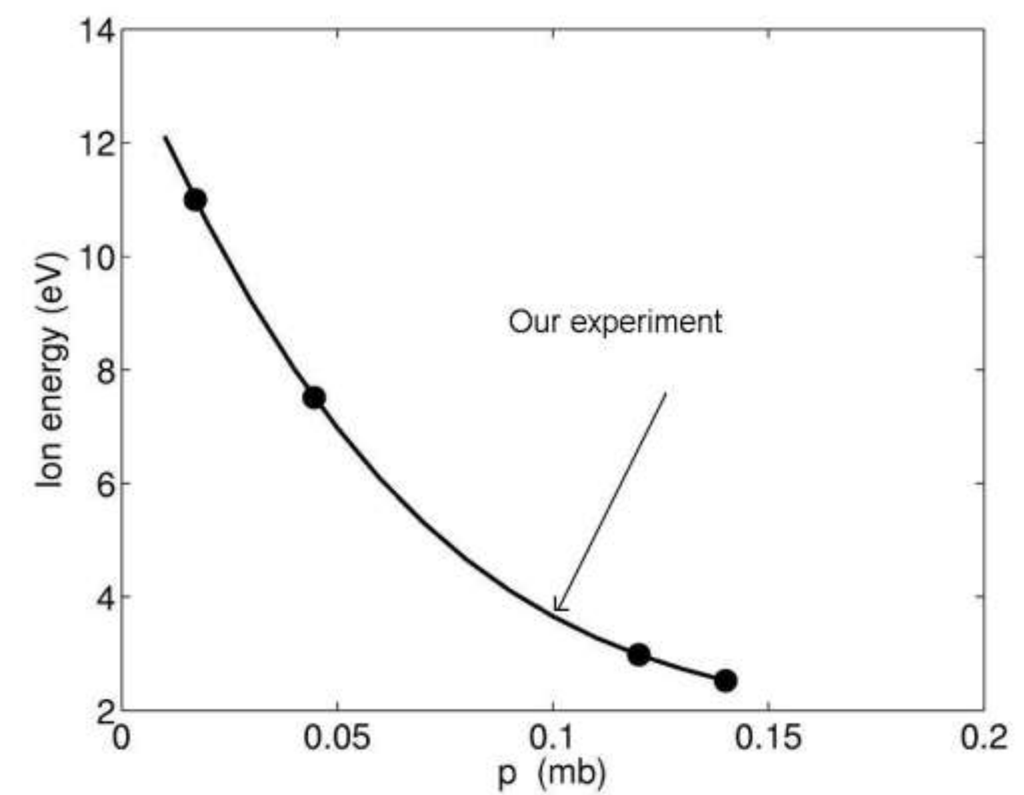
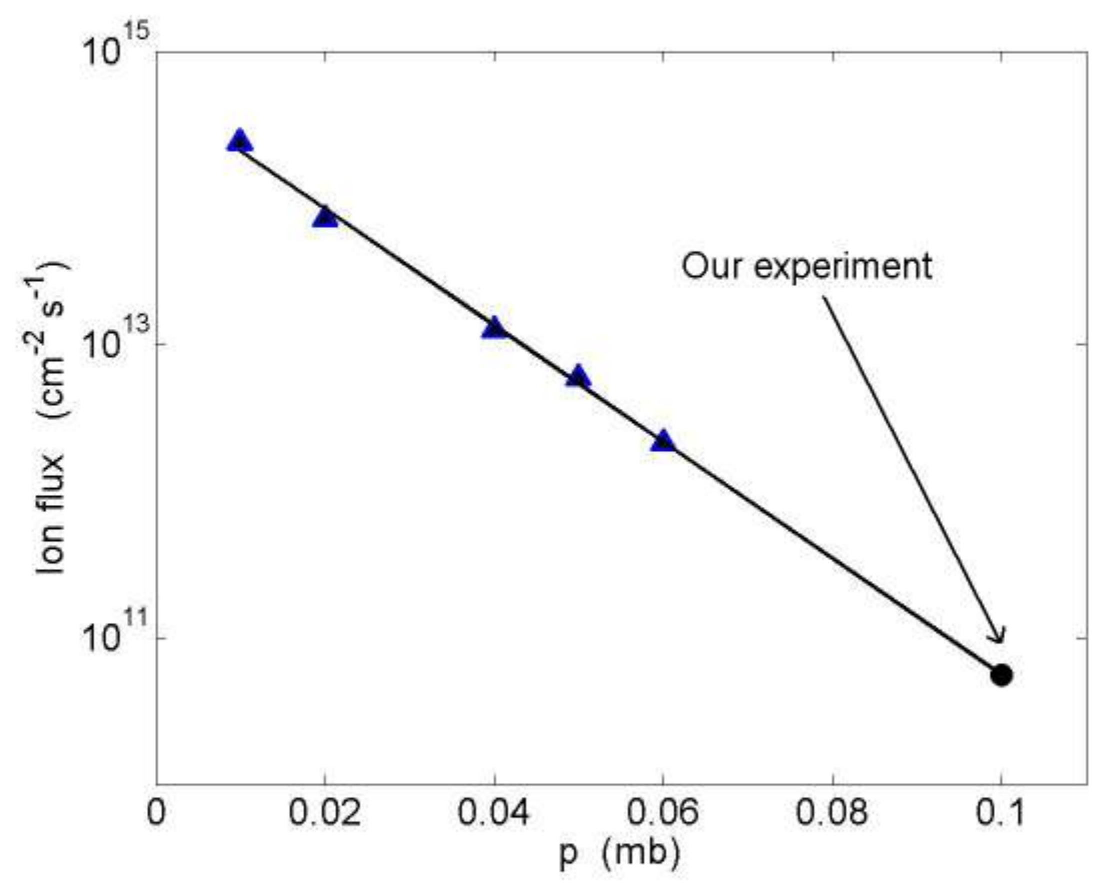
Ion energies

- At p ~ 0.1mb, the plasma sheath is collisional, so ion energy is controlled by pressure
- Mean free path inversely proportional to n_{Ar} and p



Ion flux

- We couldn't measure the current for p > 0.06 mb



Very low flux:

Φ=5.6x10^{10}cm^{-2}s^{-1}