Peculiarities of Ultrafast Irradiation Effect on the Properties of Silicon Crystals

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Presentation Structure

- **Introductory remark**
- **What we do?**
- **Why we do?**
- **How we do?**
- **Results and discussion**
- **Future Planning works**
- **Conclusions**

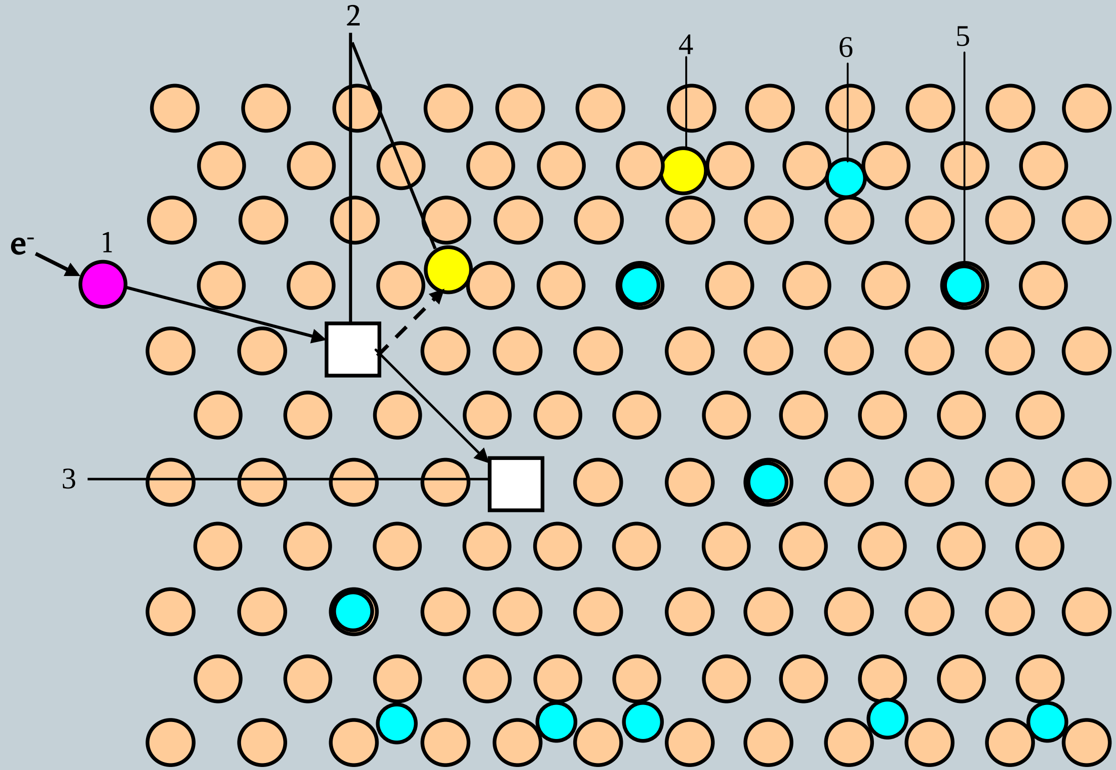
Introductory remark

- Recent trends in material science (dimensions)
- Need for time-dependant processes investigation
- Limitations of Silicon crystal – the workhorse of the semiconductor industry
- Our focus is time dependent processes in silicon crystal at irradiation.

What we do?

Fig.1. Schematic image of Si crystal lattice atoms displacements by electron irradiation:

- 1- primary removed atom,
- 2- pair (Frenkel) defects
- 3- vacancy (V),
- 4- interstitial (I) atom,
- 5 - substituted impurity atom,
- 6- interstitial impurity atom.



Why we do?

Investigation of kinetics of formation and annealing of defects induced by pulse irradiation, particularly in semiconductors and semiconductor devices, has special interest for solid state radiation physics, because it allows receiving additional information about temperature and time stability of radiation defects in materials and devices. These investigations might be applied in Space environment, nuclear reactors, in particular, to predict the application limit of semiconductor devices, their radiation and thermal stability.

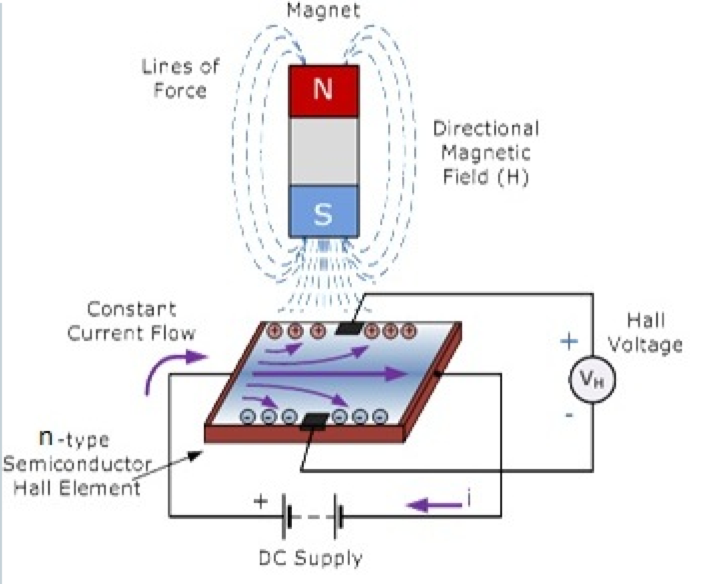
Thus, presented investigation has scientific interest for semiconductor and solid state radiation physics development and practical meaning for prediction of application limit of materials and devices in different radiation conditions.

How we do?

Samples – n-Si
d = 0.8-1mm, 3x10mm^2

Hall effect

- Magnetic field - 0.5T
- Direct current
- Temperature range - 120 – 300 K



CANDLE – Synchrotron Radiation Institute (AREAL Facility)

- Electron energy – 3.5 MeV,
- Pulse duration - 4*10^{-13}s
- Frequency – 12 Hz
- Charge - 50pC

How we do?

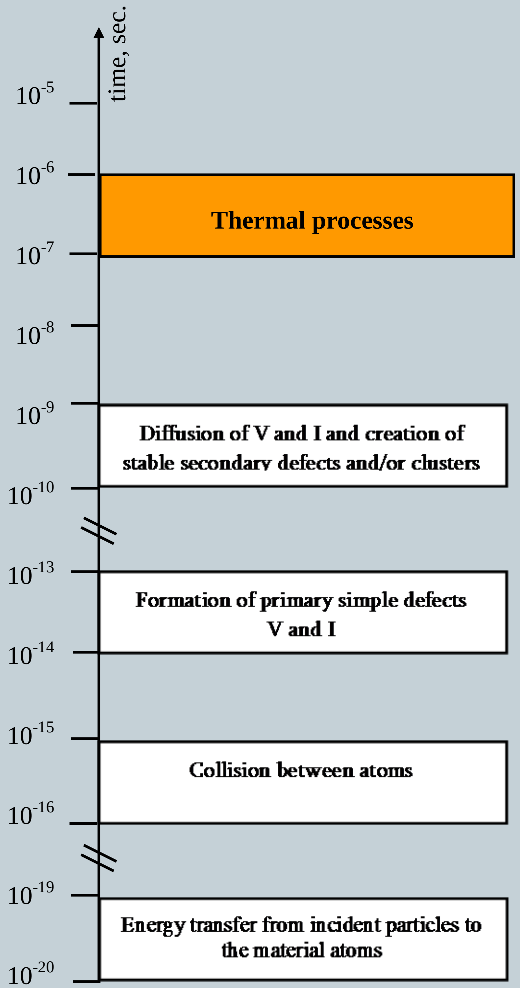


Fig2. Schematic diagram of time – scale for radiation defect formation.

Experimental methods and material characterization, "irradiation current density criterion" is given which show how irradiation beam pulse duration can effect on the material properties.

Many authors usually use for irradiation experiments conventional sources with almost microsecond pulse duration which is in the range of thermal processes formation. In our case the electron irradiation is performed at near pico-second pulse duration, hence thermal processes do not develop, and "pure" energy exchange takes place between irradiation and atoms of the matter.

Results and discussion

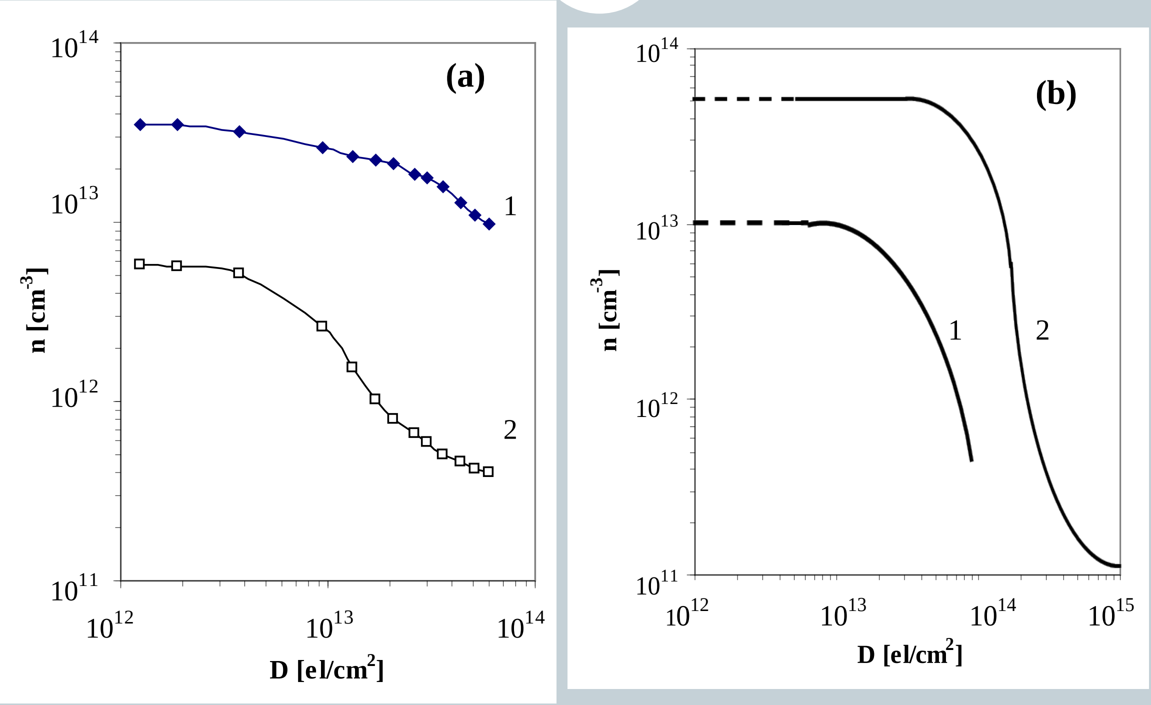


Fig.3. Silicon main charge carrier concentration dependence on electron irradiation dose: (a) – irradiation. The initial specific resistances of samples were: 1- ρ= 124 Ω·cm ; 2- ρ= 710 Ω·cm,. (b) – irradiation by electrons with energy 50 MeV; The initial specific resistances of samples were: 1- ρ= 450 Ω·cm; 2- ρ= 100 Ω·cm.

Results and discussion

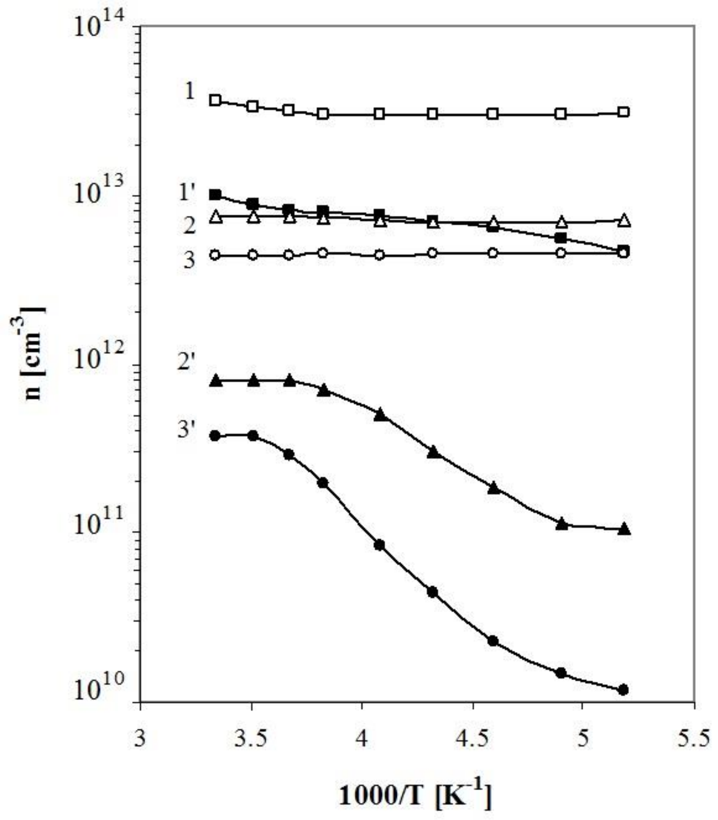
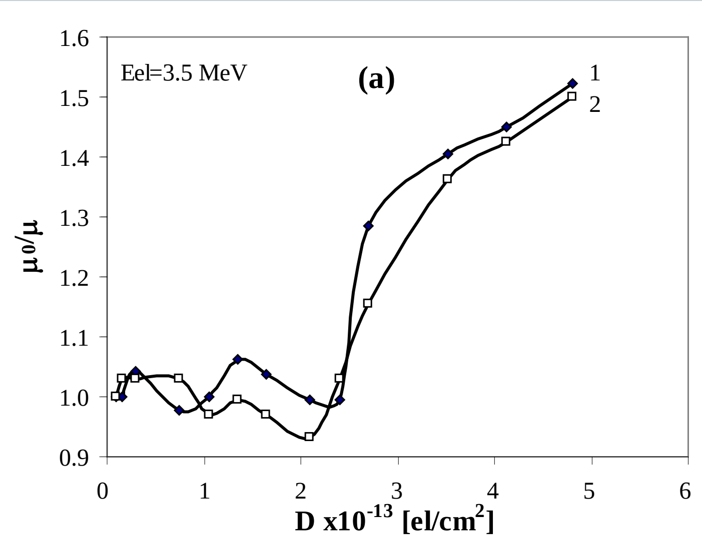


Fig.4. Temperature dependences of main charge carrier concentrations for irradiated n-Si. Specific resistances of samples before irradiation: 120 Ω·cm before (1) and after irradiation by dose 6 x 10^{13} el/cm^2 (1`) ; 720 Ω·cm before (2) and after irradiation by dose 1.2x$10^{13}$ el/cm$^2$ (2`) and 950 Ω·cm before (3) and after irradiation by dose 1.2 x 10^{13} el/cm^2 (3`). Curve slopes analyses indicate to cluster of A-centers.

Results and discussion



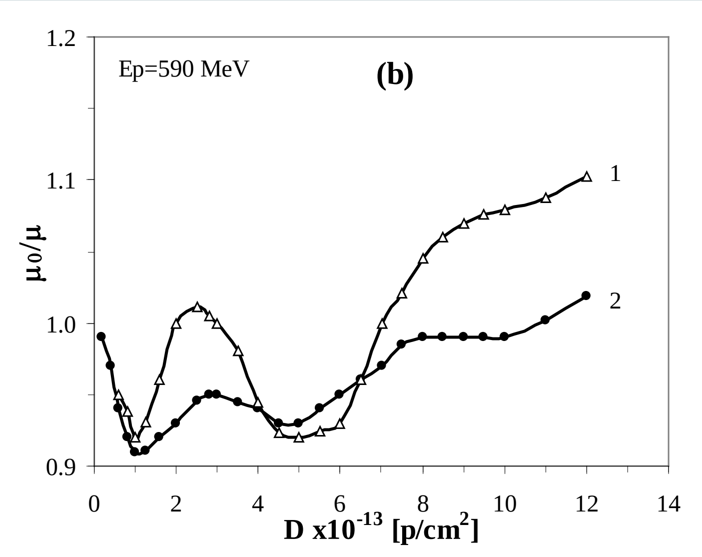


Fig.5. Silicon main charge carrier mobility (relative change) dependence on irradiation dose: (a) - electron irradiation; The initial specific resistances of samples were: 1- ρ= 124 Ω·cm ; 2- ρ= 710 Ω·cm,. (b) – irradiation by protons with energy 590 MeV; Initial specific resistances of samples were: 1- ρ=0.11Ω·cm; 2- ρ=0.46 Ω·cm. The irradiation and measurements were carried out at room temperatures. The same behavior is obvious as clusters of radiation defects.

Results and discussion

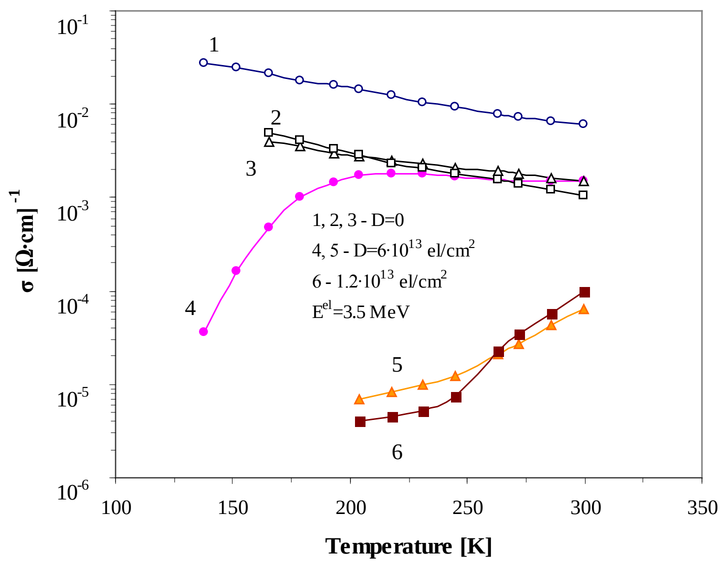


Fig.6. Silicon crystal (n-Si) electrical conductivity temperature dependence after electron pico-second beam irradiation (energy 3.5 MeV). Samples specific resistivity: 100 Ω·cm, 1 – before irradiation, 4 – after irradiation by $6 \cdot 10^{13}$ el/cm^{2}dose; 700 Ω·cm, 2 - before irradiation, 5 - after irradiation by dose $6 \cdot 10^{13}$ el/cm^2; 950 Ω·cm, 3 - before irradiation, 6 - after irradiation by $1.2 \cdot 10^{13}$ el/cm^{2}dose.

Conclusions

- Pico-second electron irradiation, in spite of low intensity has a significant effect on the electrical physical properties of silicon crystal.
- It was shown that stable at room temperatures radiation defect formation in silicon crystal takes place in stages; at first phase defects are formed as vacancy and interstitial atoms which subsequently gather into clusters, although cluster formation in Si crystal at 3.5 MeV electron energy irradiation is difficult.
- Study of temperature dependence of charge carrier mobility helped to reveal their scattering mechanism: scattering on the ionized impurities and on the radiation defects.
- It was reviled that the “critical dose” corresponding to sharp changes of electrical-physical properties depends on specific resistivity. In these cases it is found to be more appropriate to use an expression “dose threshold” of cluster formation instead of the more commonly used “energy threshold”.

General conclusion: AREAL is A - REAL Facility gives nice reality.

Thank You For Your Attention!!!

Acknowledgement

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