The Sequential Proton-Electron Irradiations' Effects on n- and p-type Silicon Single Crystals

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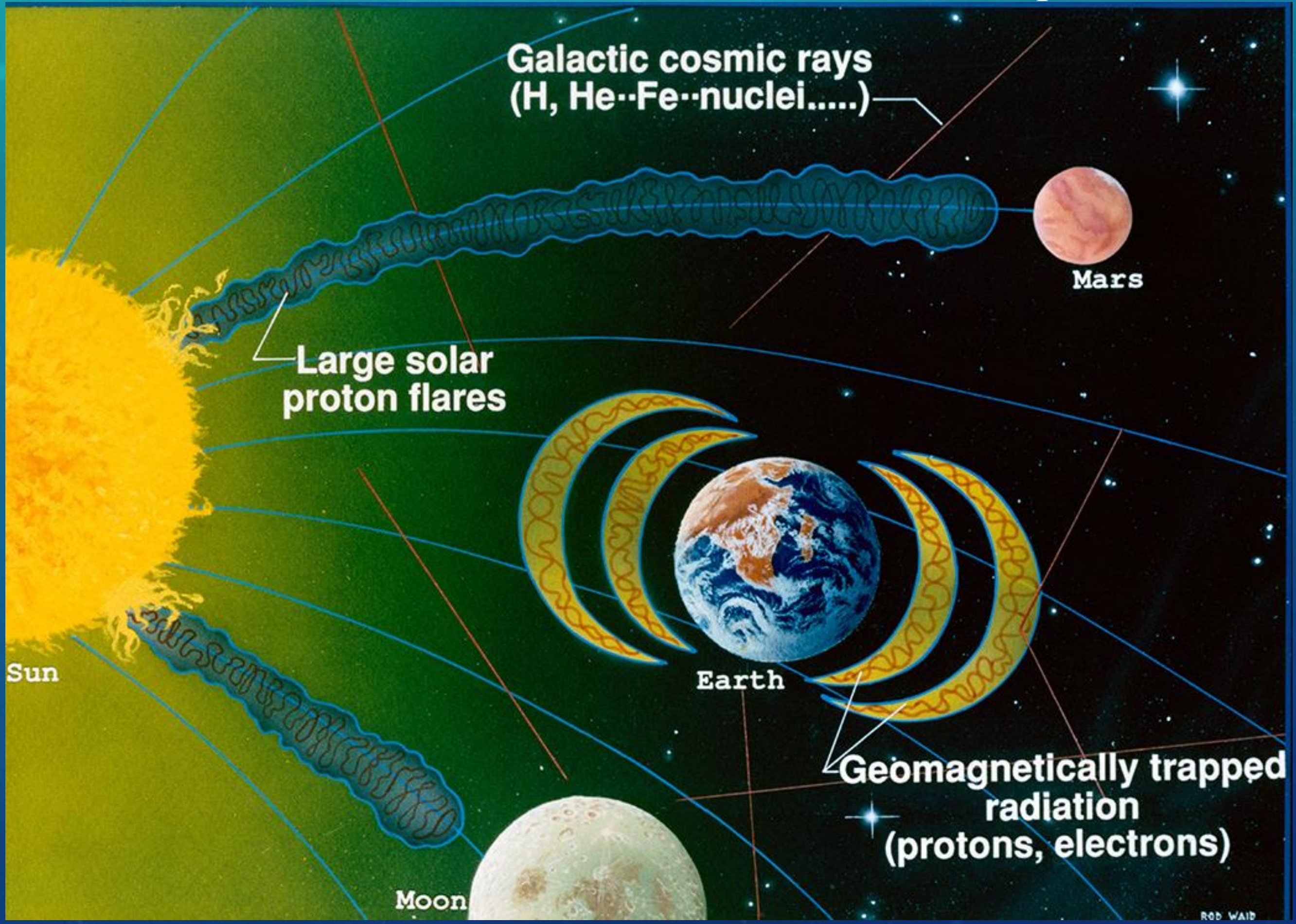
Motivation

One of the important features of these natural radiation environments is that electronic devices are simultaneously exposed to irradiation by several types of high-energy particles. The most intense of which are protons and electrons with energies of several MeV. The sequentially irradiation of semiconductors by protons and electrons allows to simulate natural radiation environment processes.



Aim

The aim of this work is to study the effect of sequential proton-electron irradiation on the parameters (charge carriers' concentration and mobility, resistivity) of silicon crystals.

To accomplish this silicon single crystals were irradiated with an 18 MeV energy proton such a dose at which the samples still retain their semiconductor properties, and then were irradiated with an ultrafast electron beam with an energy of 3.5 MeV.

Irradiation Parameters

Proton irradiation-Radioisotope Production Center at AANL

- energy of 18 MeV,
- intensity of 10^{12} $p \cdot cm^{-2} \cdot s^{-1}$
- mean current of 1μA,
- irradiation doses of 10^{13} - $5 \cdot 10^{14}$ p/cm^2.

Electron irradiation- AREAL facility at CANDLE Synchrotron Research Institute

- energy of 3.5 MeV,
- pulse duration of $4 \cdot 10^{-13}$ second,
- frequency of 12 Hz,
- an impulse charge of 70 pico-Coulomb.

Radiation Defects in Semiconductor Silicon Crystals

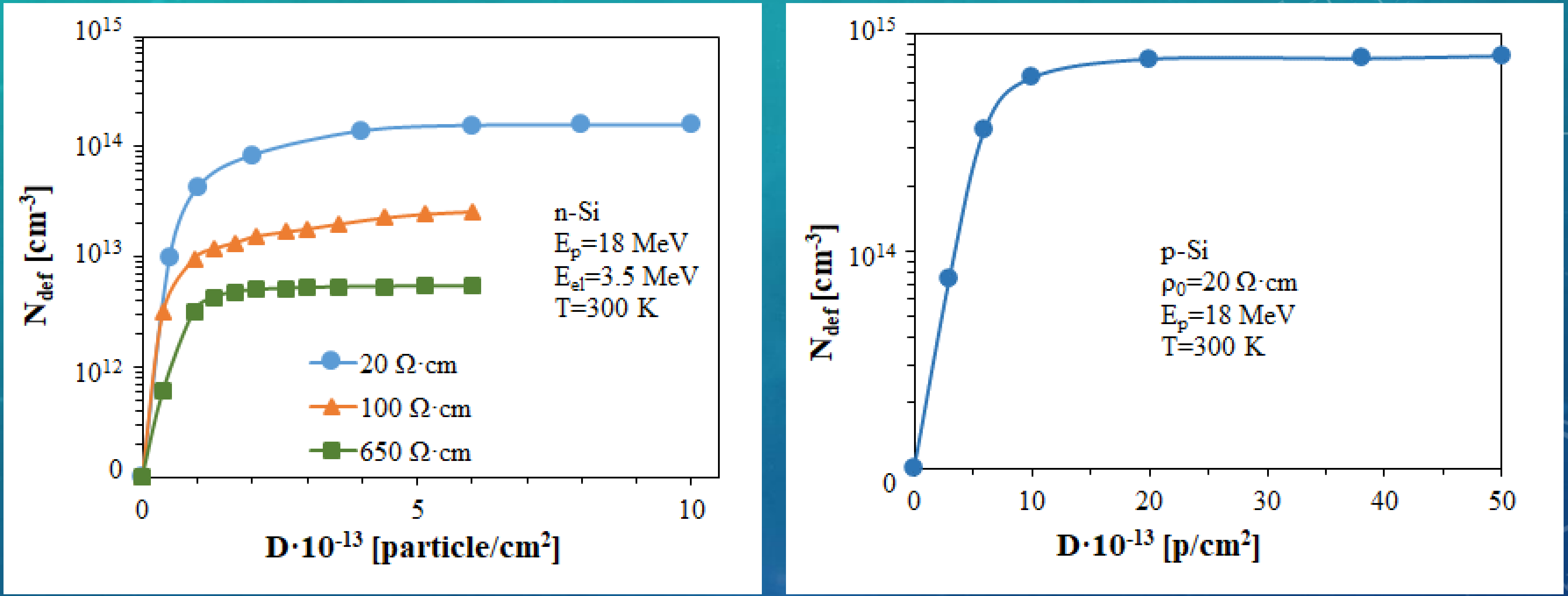


Fig. 1. Radiation defect concentration vs irradiation dose for proton and electron irradiation of n- and p-type silicon crystals. The sample with a resistivity of 20 Ω·cm was irradiated by 18 MeV energy protons, while the 100 Ω·cm and 650 Ω·cm samples were irradiated using a picosecond-pulsed 3.5MeV energy electron beam.

Radiation Defect Concentration

The concentration of radiation defects in n-type and p-type silicon crystals induced according to the irradiation dose can be interpolated by means of the empirical exponential function (1):

$$N_{def} = n_0 - n(D) = n_0(1 - \exp(-D/D_0)),$$

where n_0 is initial charge carrier concentration, $n(D)$ is their concentration at a given irradiation dose D delivered at room temperature, and D_0 is the irradiation dose at which the carrier concentration $n(D)$ at a temperature T = 300 K decreases by a factor of e in the irradiated semiconductor samples.

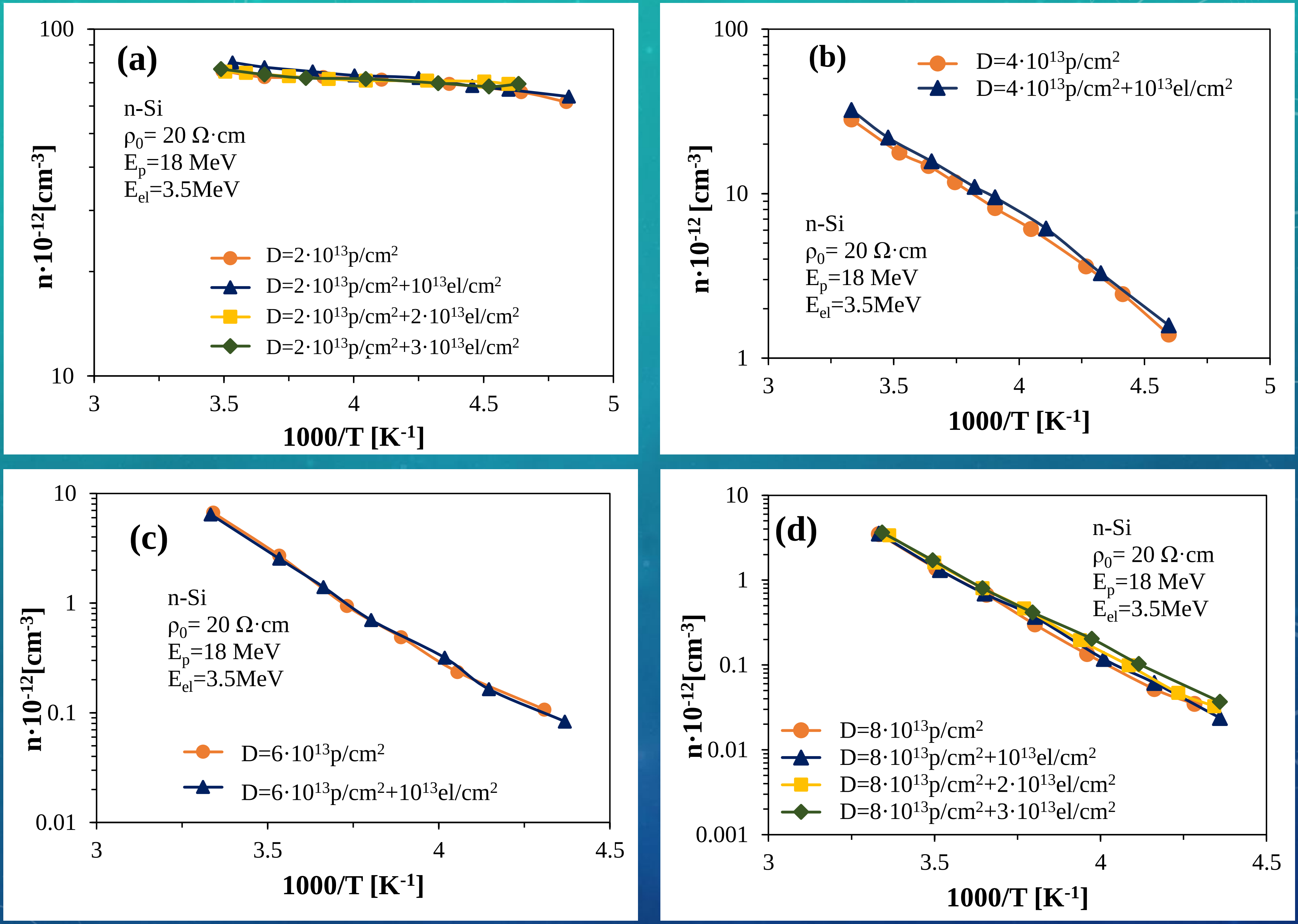


Fig. 2. Temperature dependence of charge carrier concentration in n-type silicon crystals irradiated by 18MeV energy protons and 3.5MeV energy electrons with different doses.

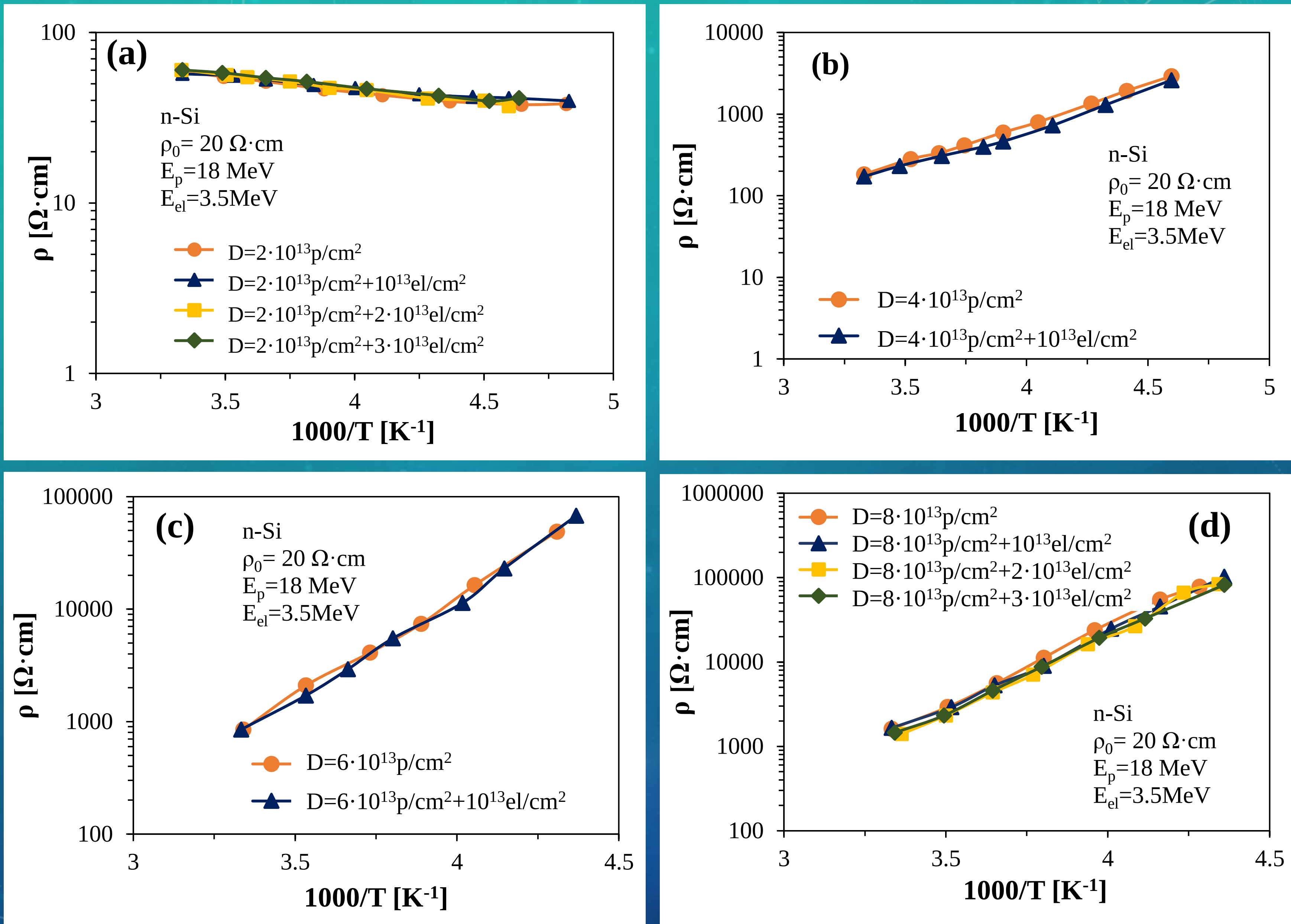


Fig. 3. Temperature dependence of resistivity of n-type silicon crystals irradiated by 18MeV energy protons and 3.5MeV energy electrons with different doses.

The concentration of charge carriers irradiated by 3.5 MeV electrons

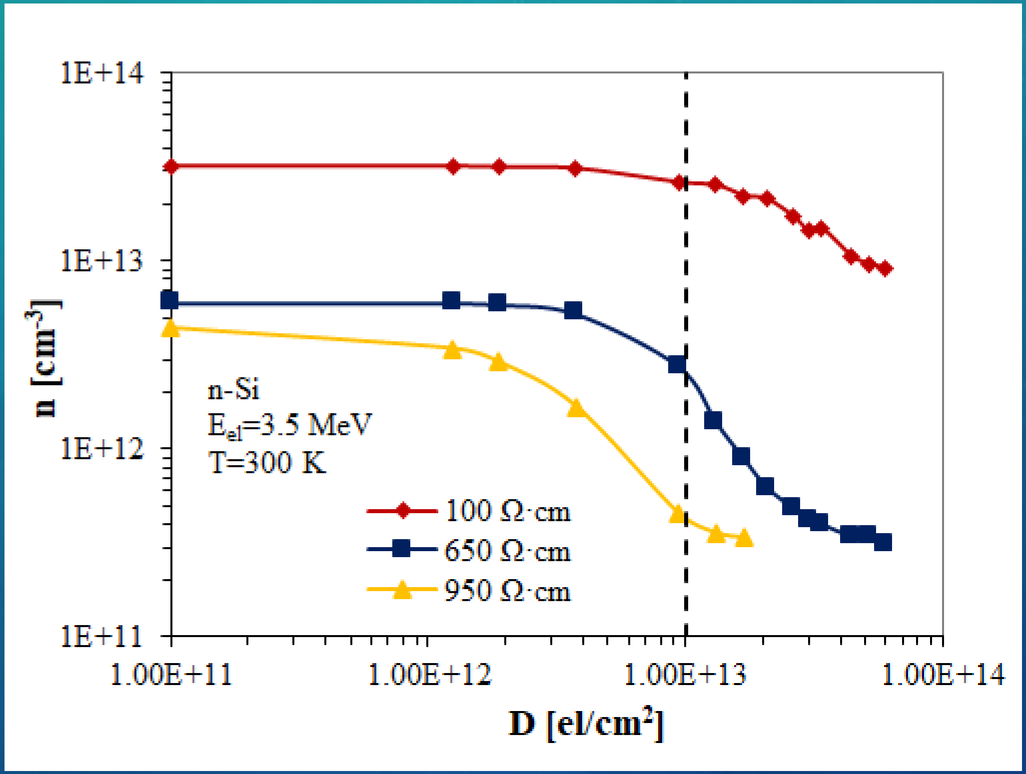


Fig. 4. Dose dependence of charge carrier concentration in n-type silicon crystals irradiated by 3.5MeV energy ultrafast electrons with different resistivities.

Conclusion

- ❖ The concentration of radiation induced defects, determined as a function of irradiation dose, can be interpolated by means of the same empirical exponential function as was used for the electron irradiation measurements.
- ❖ It can be assumed that proton irradiation creates radiation resistance of the sample parameters to sequential irradiation with electrons in the studied doses.

Thank You for Your Attention!