Pictures to: Low Temperature Electron Irradiation Damage in Silicon

Here are the pictures to the "electron irradiation" part of my thesis. Their size is about what you would have produced on photographic paper in the dark room.

- These pictures are not very exciting but resulted from a lot of work. What follows are firstly the pictures used in my thesis paper (and in the publication)
  The I show a few additional pictures just to demonstrate the weirdness often encountered.
  Altogether I took around 700 pictures in total. .

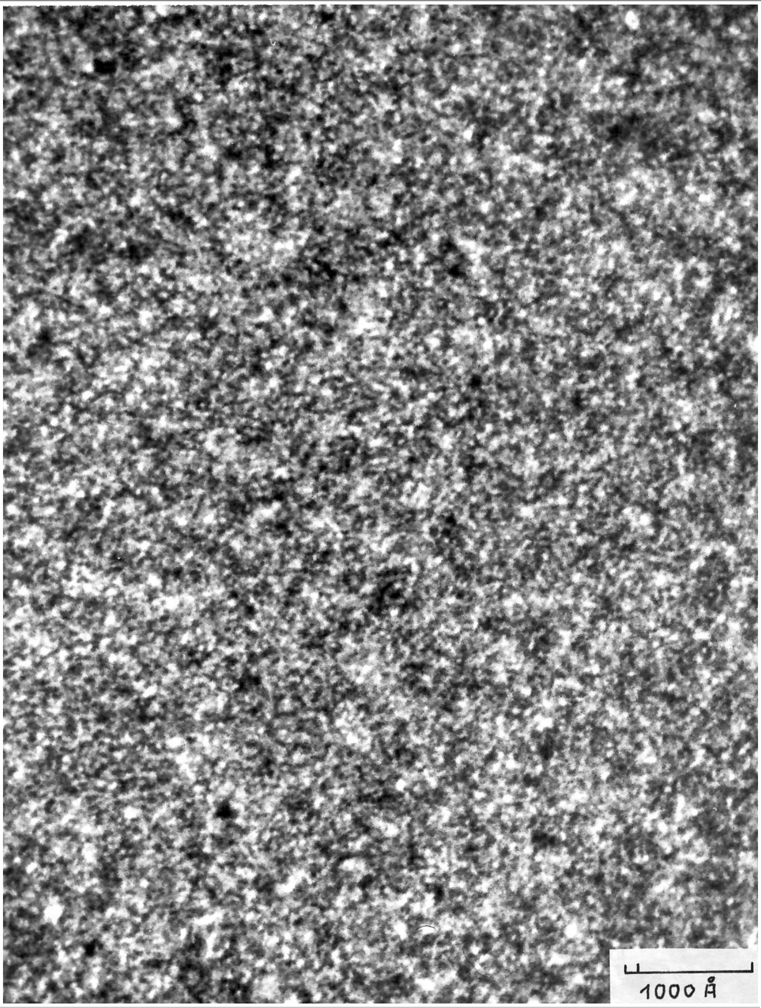


Fig. 5.1 in Thesis. Similar to Fig. 1 in publication. "Weak Beam" conditions as in all other pictures if not explicitly stated.

Original figure caption:
Schädigungsstruktur bei T < 40K
T_{Bestr}=20K, D ≈ 5 · 10^{22} e^-/cm^2, E_e=600 keV, 10 Ωcm p-type Si

Figul'e 1. Weak-beam micrograph of 50 Ωcm n-type silicon irradiated with about 50 x 10^{11} electrons/cm^2 at 35 K.

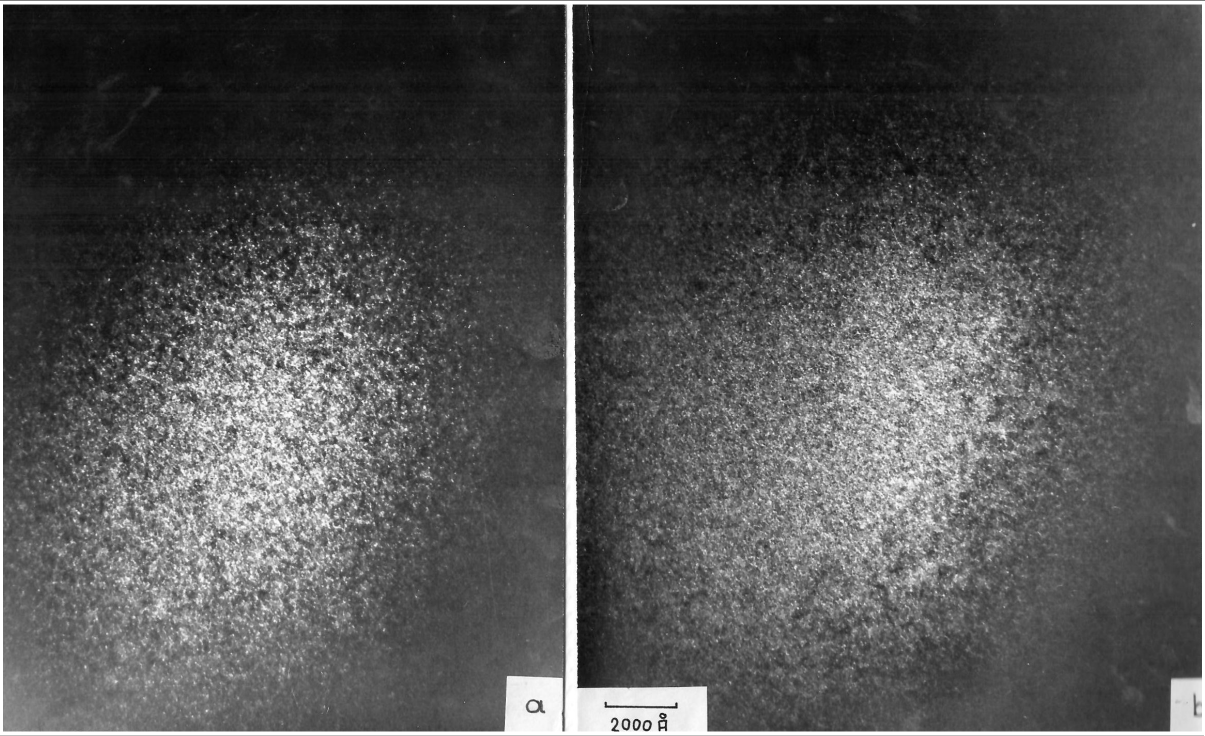


Fig. 5.2 in Thesis. Fig. 2 in publication.

Original figure caption:
Zeitliche Änderung der Schädigungsstruktur bei
T_{Bestr}=35K, E_e=650 keV, Ωcm p-type Si, (a) D ≈ 3 · 10^{22} e^-/cm^2, (b) D ≈ 5 · 10^{22} e^-/cm^2

Figure 2. Dose dependence of the damage structure in 50 Ωcm n-type silicon irradiated at 3S K.
(a) Dose 3 x 10^{12}electrons/cm^2
(b) Dose 5 x 10^{12} elcctroms/cm^2

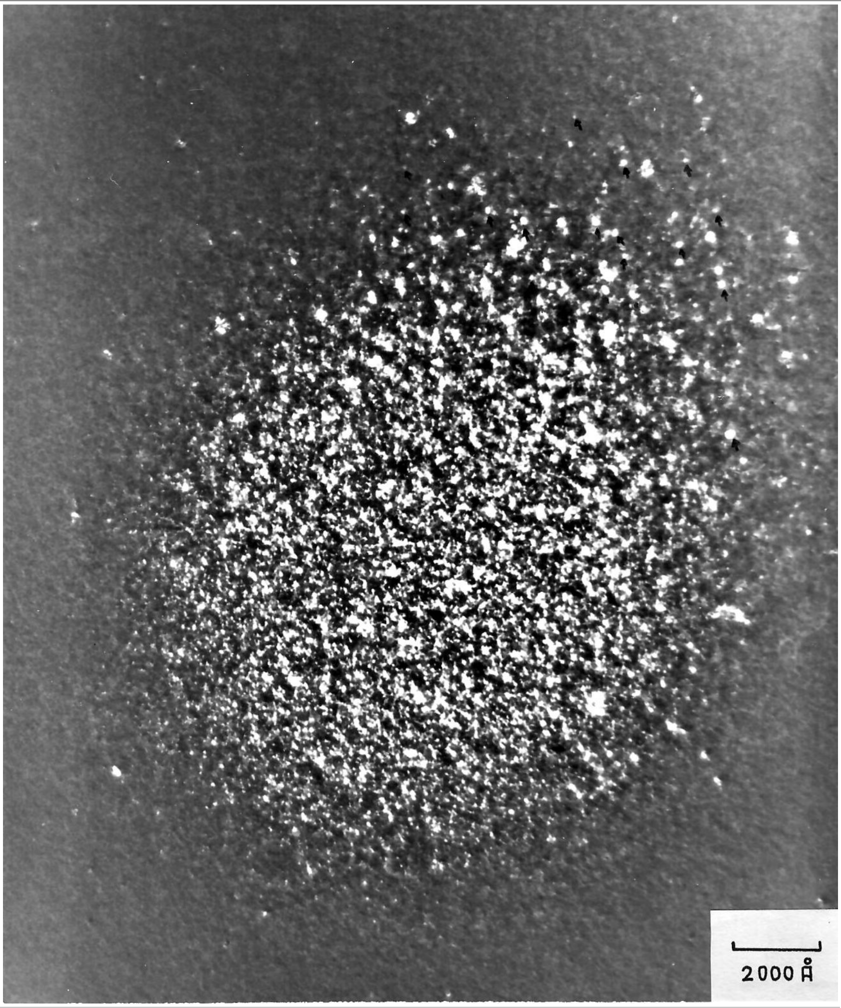


Fig. 5.3 in Thesis; Fig. 3 in publication.

Original figure caption:
Schädigungsstruktur bei 40K < T < 60K
T_{Bestr}=40K, D ≈ 5 · 10^{22} e^-/cm^2, E_e=600 keV, 50 Ωcm p-type Si

Figul'e 1. Weak-beam micrograph of 50 Ω cm n-type silicon irradiated with about 50 x 10^{12} electrons/cm^2 at 40 K.

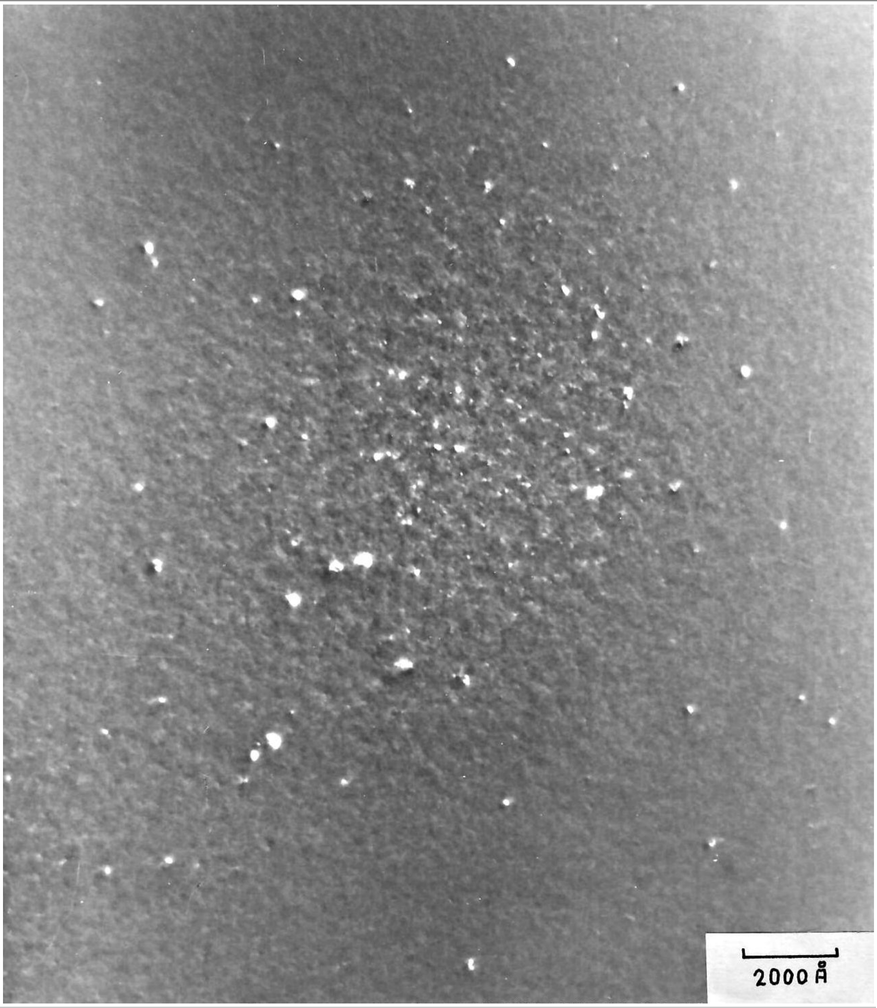


Fig. 5.4 in Thesis; Fig. 4 in publication.

Original figure caption:
Schädigungsstruktur bei T=60K
T_{Bestr}=60K, D ≈ 5 · 10^{22} e^-/cm^2, E_e=650 keV, 50 Ωcm n-type Si
Die großen sichtbaren Kontraste sind nicht von der Bestrahlung sondern von der Probenpräparation

Figul'e41. Weak-beam micrograph of 50 Ωcm n-type silicon irradiated with about 5 x 10^{12} electrons/cm^2 at 60 K. The big white spots are not due to irradiation but to sample preparation

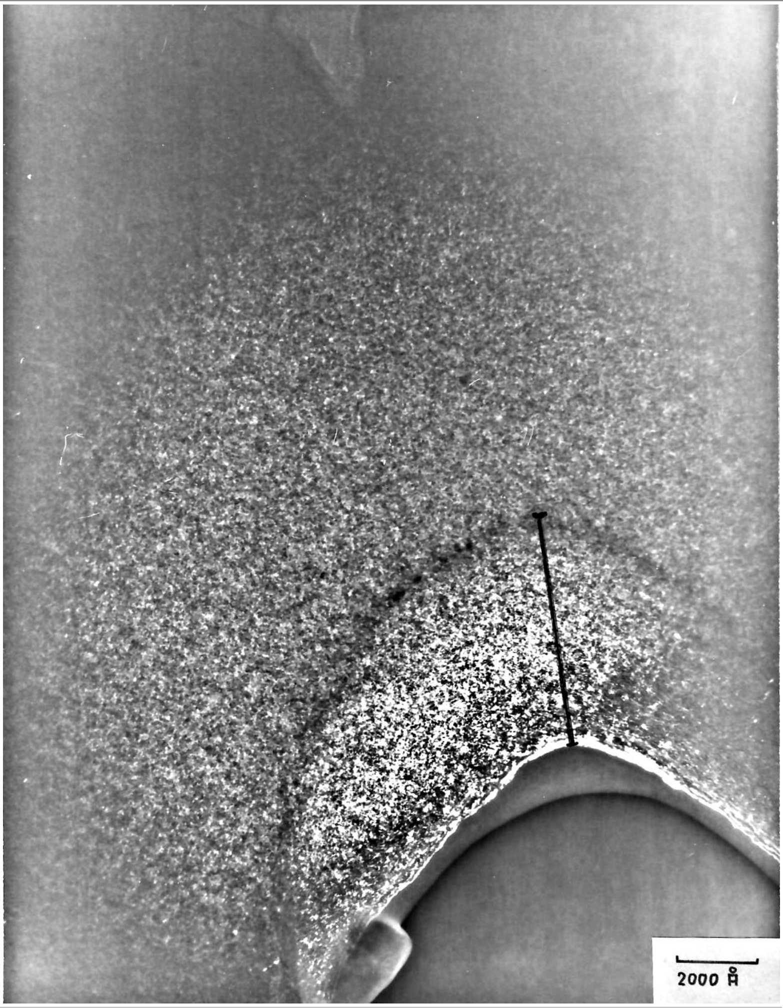


Fig. 5.4 in Thesis; Fig. 1 in publication.

Original figure caption:
Scädigungsstruktur bei 30 K in einer keilförmigen Probe

In hindsight, those picture tells it all. The defect density does not depend on the specimen thickness - i.e. they are not homogeneously distributed in the volume but located in a (surface-near) layer. That the defects are brighter is due to reduced thickness.

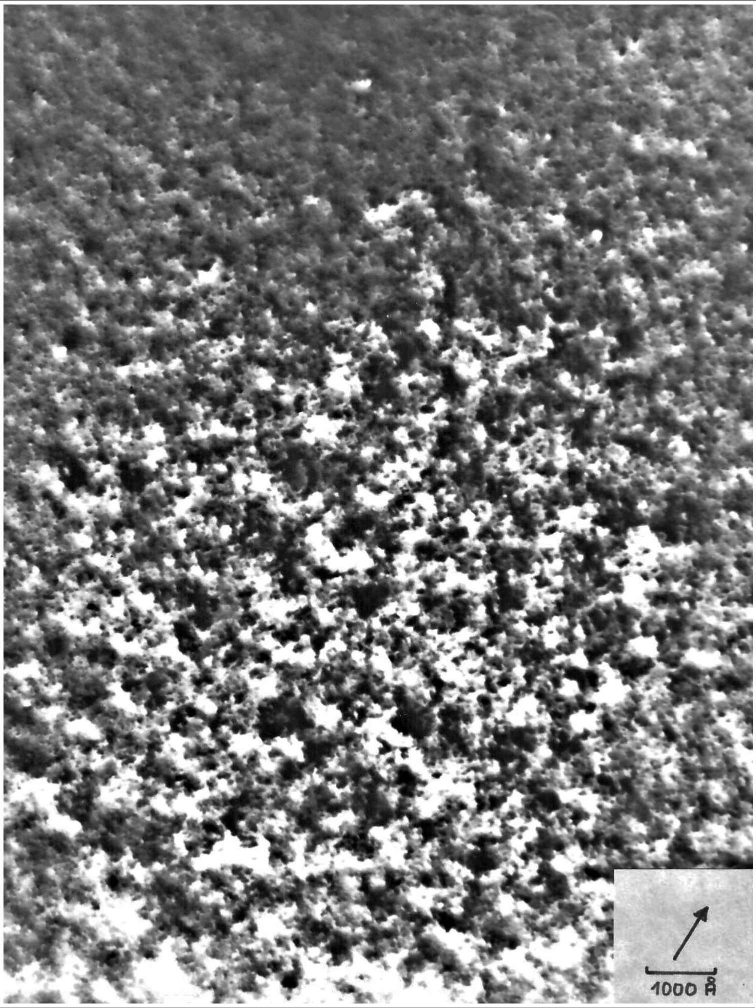


Fig. 5.6 in Thesis.

Original figure caption:
Dunkelfeldaufnahme eines bei T=40K erzeugten Schädigungsmusters

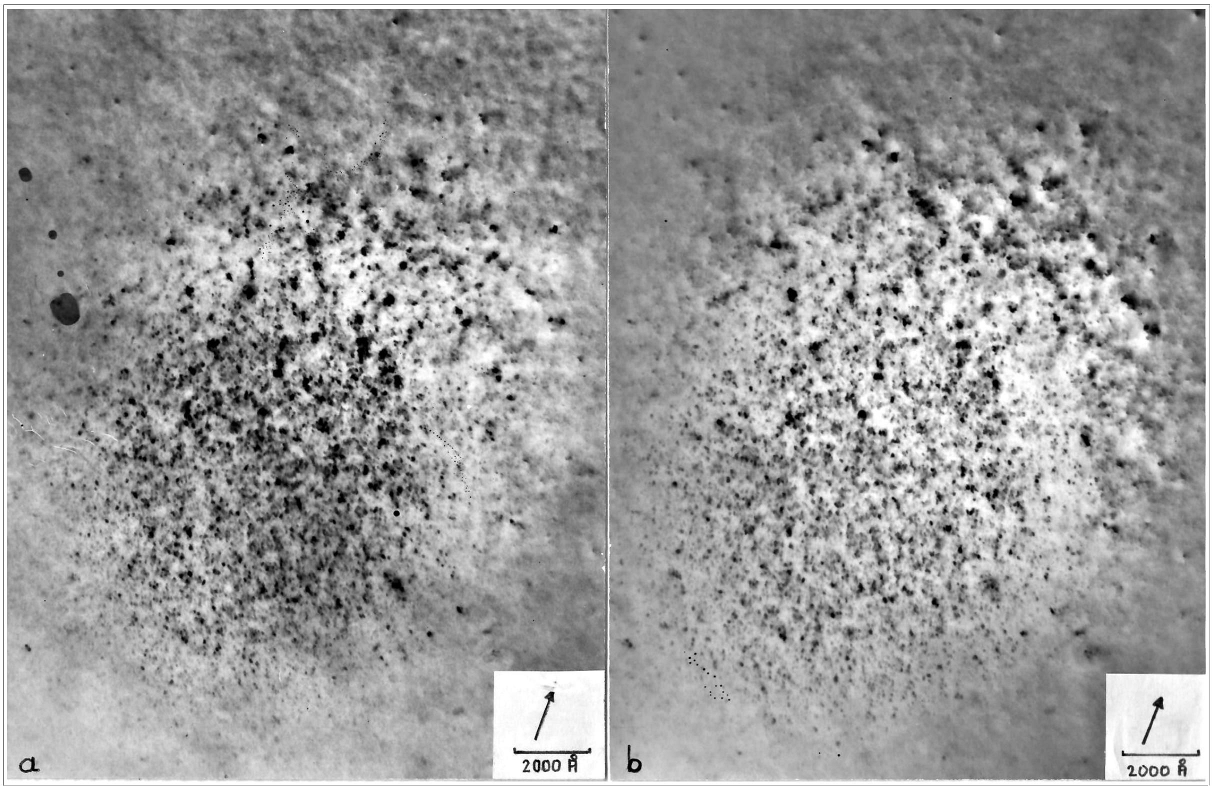


Fig. 5.7 in Thesis.

Original figure caption:
Änderung der Defektstruktur einer bei T=40K bestrahlten Probe durch Aufwärmen auf Raumtemperatur.
(a) Schädigungsstruktur bei T=40K
(b) Schädigungsstruktur bei T=300K

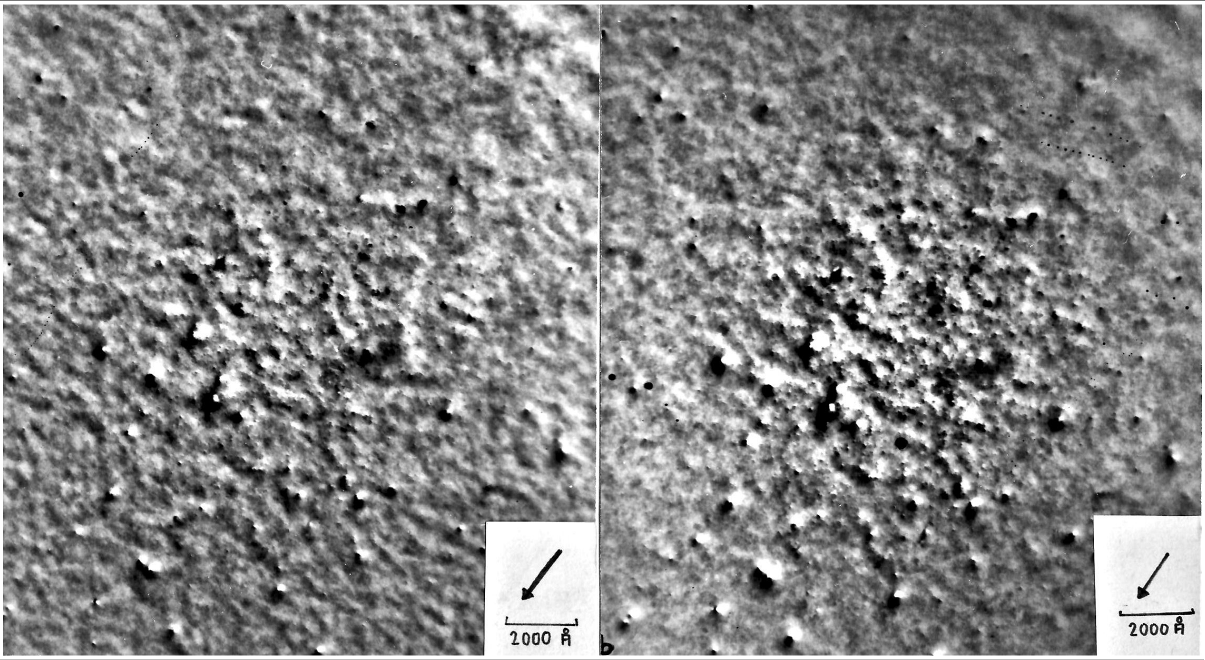


Fig. 5.8 in Thesis; Fig. 5 in publication.

Original figure caption:
Änderung der Defektstruktur einer bei T=60K bestrahltemn Probe durch Aufwärmen auf Raumtemperatur.
(a) Schädigungsstruktur bei T=60K
(b) Schädigungsstruktur bei T=300K
Abbildung im dynamischen Dunkelfeld. Die großen Schwarz-Weiß Kontraste sind durch die Präparation verursacht.

Figure s. Dynamical dark-field micrographs of 50 Ωcm n·type silicon irradiated with approximately 5 X 10^{22} clectrons/cm^2 at 60 K. The big black-white contrasts are not due to irradiation but to sample preparation. (a) Immediately after irradiation at 60 K, (b) after warming to room temperature.

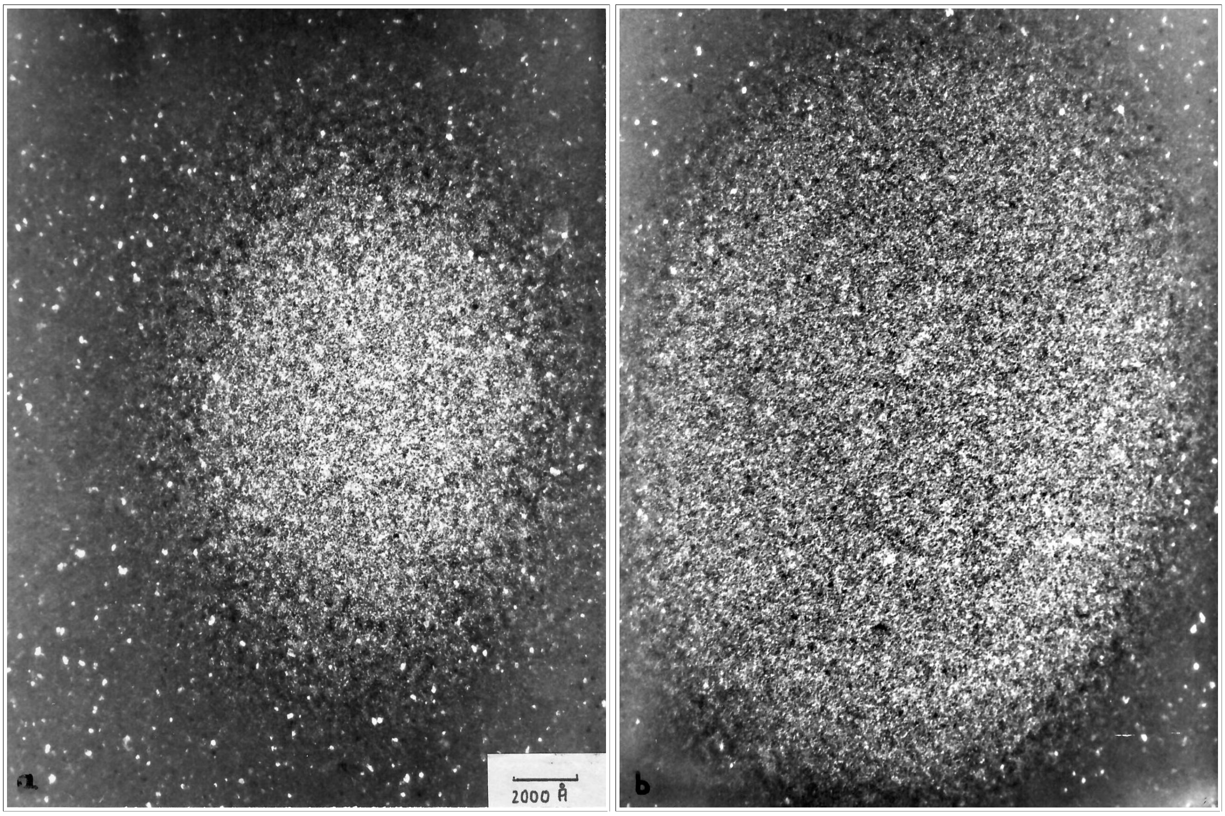


Fig. 5.9 in Thesis (a) left, (b) right; Fig. 6 in publication.

Original figure caption:
Spannungsabhängigkeit der Defektstruktur.
(a) T_{Bestr}=20K, D=5 · 10^{22} e^-/cm^2, E_e=600 keV, 20 Ωcm p-type Si
(b) T_{Bestr}=60K, D=5 · 10^{22} e^-/cm^2, E_e=650 keV, 20 Ωcm p-type Si

Figure 6. Weak-beam micrographs of the damage structure in 10Ω cm p-type silicon at 20 K. The big white and dark spots are not due
to irradiation but to sample preparation.
(a) $E_{electrons}$=600 keV, dose ca. 5 X 10^{22} electrons/cm^2 (b) Eelectrons=650 keV, dose ca. 3·6 X1Q^{22} eiectrons/cm^2

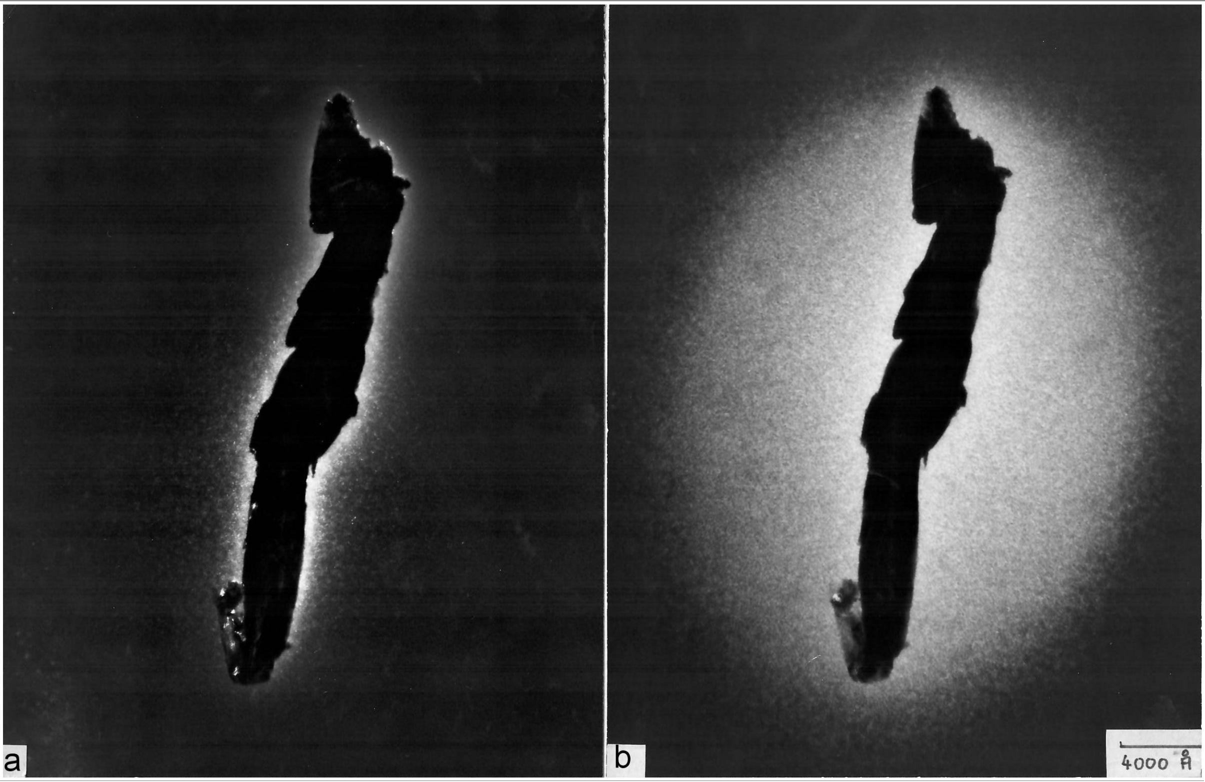


Fig. 5.10 in Thesis.

Original figure caption:
Schädigung in der Umgebung eines Schmutzpartikels.
T_{Bestr}=20K, 900 Ωcm p-type Si
(a) D=1,5 · 10^{22} e^-/cm^2,
(b) D=1,5 · 10^{22} e^-/cm^2

That picture nakes clear that "shot-in" dirt causes nucleation of the defects only close to the top êsurface.

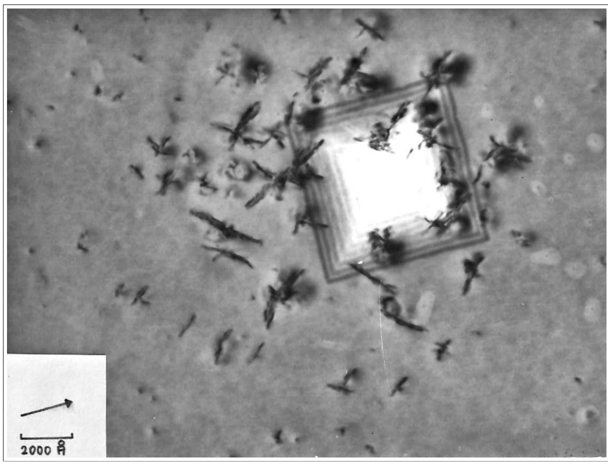
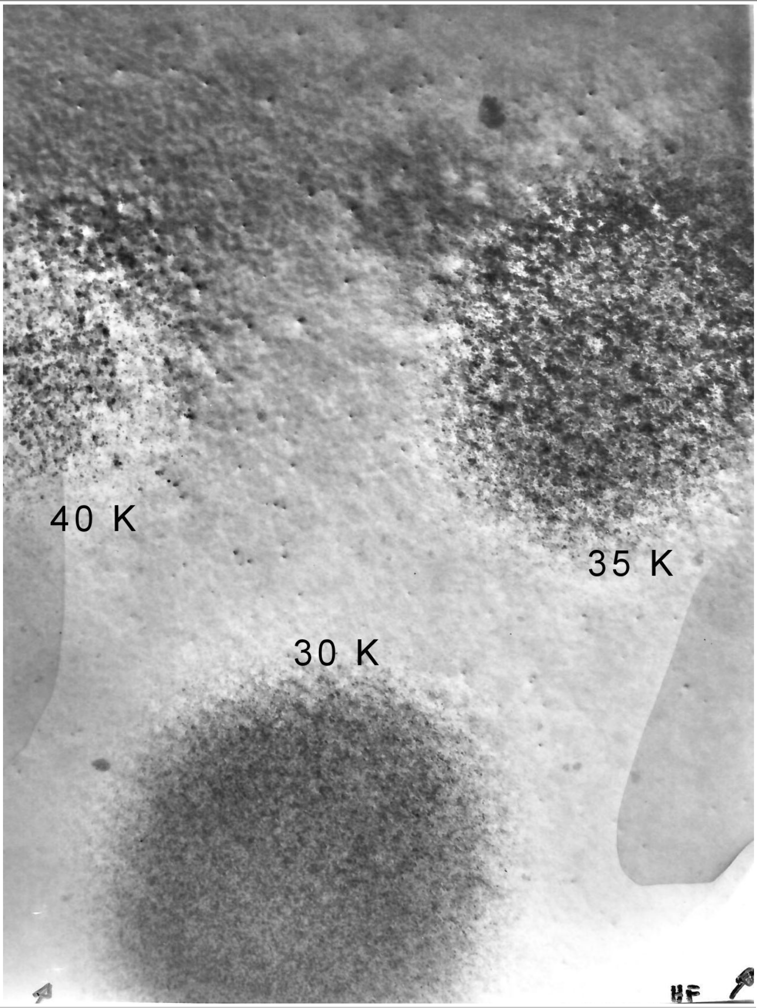


Fig. 6.1 in Thesis.

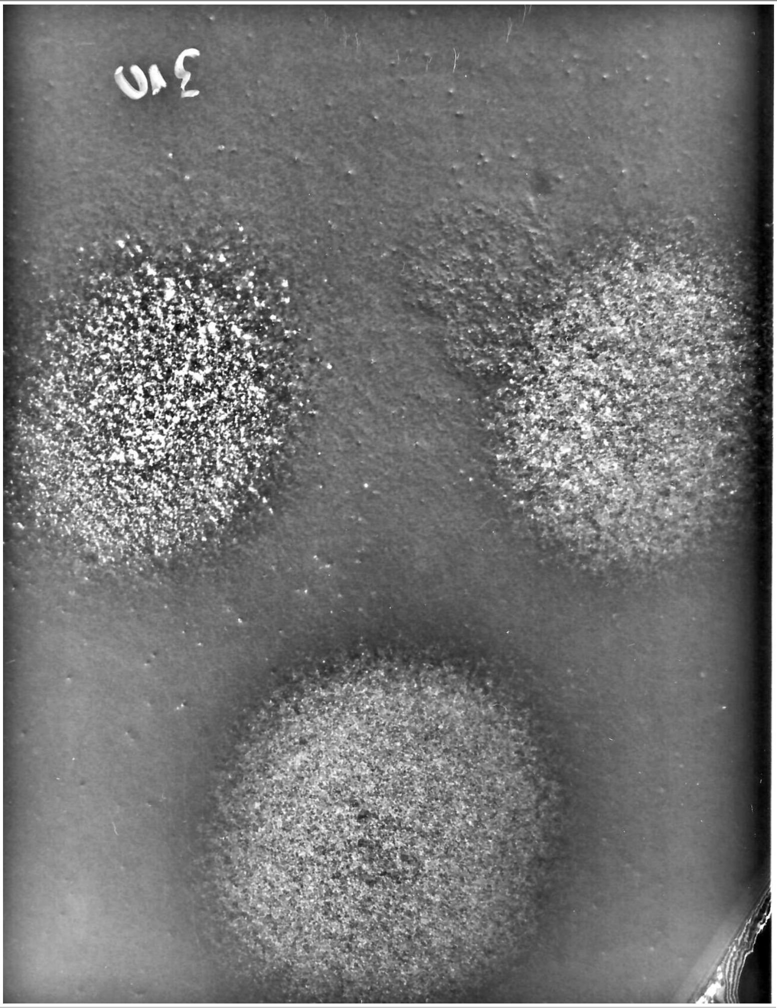
Original figure caption:
Strhelnschädigung in Germanium

A quick try-out. No damage similar to what was seen in Si occurs, even at very high doses. The big visible defects resulted very likely from ion damage inside the microscope.

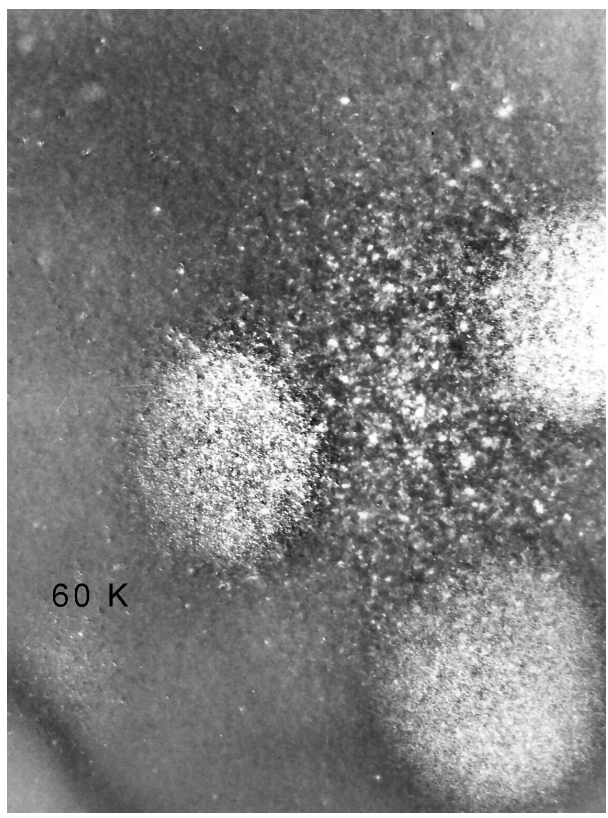
Next a few additional pictures just to demonstrate the weirdness often encountered in this kind of research



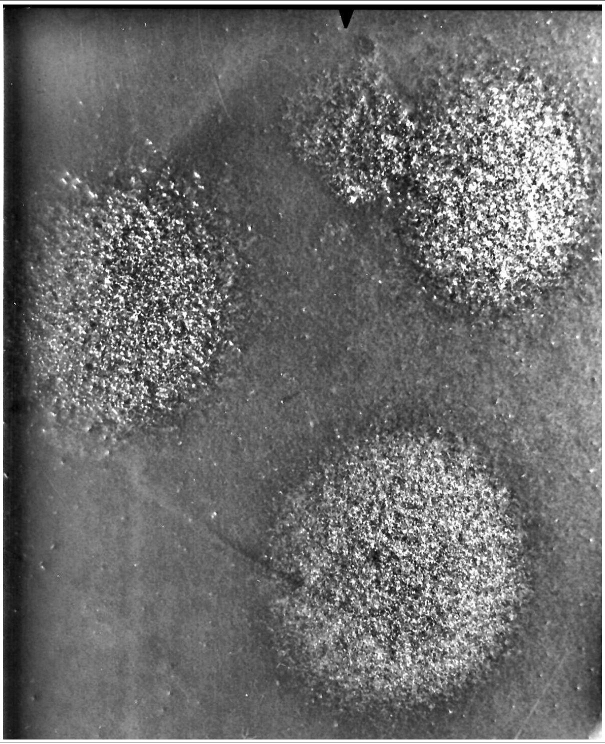
Kinetic brightfield picture e taken at 40 K after irradiating three areas at the temperatures indicated .
Note that the appearance of the damage changes very much within a temperature interval of just 10 K!
Note also that there isn't much to be seen in the the area between the spots.
The picture was taken in May 20th 1974.
There is no scale but the sport size is about 1 µm.



Weak-beam picture taken at room temperature on May 21st, one day after the picture above.
All you see is that not much has changed, which by then was what I expected from older results.
So far so good. But now look at the picture taken 3 day later, at May 24th:



Weak-beam picture taken at room temperature on May 24th, four day after the irradiation..
This picture also shows a fourth spot of irradiation at 60 K (lower left hand corner) with very little damage to see.
This is, however, of no importance in the present context.
A lot of "big" defects have appeared in the area between the irradiated spots.
It is not too difficult to come up with some hypothesis of what might have happened. But we don't need to bother,
just look at the following picture taken 3 days later:



Weak-beam picture taken at room temperature on May 27th, three day after the picture above with the additional defects.
All those "new" defects have disappeared. What we see is pretty much the same as one day after the irradiation shown two pictures above.

There is only one conclusion. In scientific terms: Weird shit happens in irradiated Silicon.
And this is only one example of weird shit encountered in this work. Being a conscientious (or possibly just lazy) scientist, none of this was included in my thesis.
The only reference made to all that strange stuff (at least half a year of work and encompassing several 100 pictures) is (on page 72):
"Die Abhängigkeit der Agglomerationsgeschwindigkeit von der Beschleunigungsspannung ... ist bislang *völlig unvwerstanden*. Dieses Beispiel (*neben einer Reihe hier aus Gründen der Übersichtlichkeit nicht aufgeführten ebenfalls unverstandenerr Effekte)...*..