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Publication Date

1975-11-01

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Presented at the 1975 IEEE Nuclear Science
Symposium, San Francisco, CA,
November 19 - 21, 1975

LBL-3878
c.1

THE EFFECT OF DISLOCATION ON THE ENERGY RESOLUTION OF HIGH-PURITY GERMANIUM DETECTORS

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November 1975

Prepared for the U. S. Energy Research and
Development Administration under Contract W-7405-ENG-48

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DISCLAIMER

THE EFFECT OF DISLOCATION ON THE ENERGY RESOLUTION OF HIGH-PURITY GERMANIUM DETECTORS*

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SUMMARY

The energy resolution of high-purity Ge detectors depends on the dislocation density and distribution in the single crystal. This correlation could be shown in a number of planar detectors with different dislocation densities. Scanning with collimated electrons and gamma-rays revealed the strong dependence of local detector performance on dislocation density.

INTRODUCTION

The energy resolution of high-purity Ge planar detectors is sometimes worse than one would expect from charge production statistics and electronic noise.[1] Frequently, the resolution depends on the particular single crystal under examination and often on the position in the crystal of the slice examined. In particular, we observe that detectors made from the lower part of high-purity germanium single crystals sometimes show a poorer spectrometric performance than those taken closer to the 'seed' end.

This observation can be explained either by trapping due to chemical impurities which create deep levels or by incomplete charge collection due to the presence of dislocations. Since both the concentration of impurities and often times the density of dislocations increase towards the tail of a crystal it is not immediately evident which one is the cause for the poor charge collection. We conclude from studies on many planar detectors that in our case, the dislocations are the main cause. Deep level impurities rarely effect the resolution. Detectors manufactured from germanium slices showing a high dislocation density ($> 10^4$ cm^{-2}) and inhomogeneous dislocation distribution always exhibit assymmetric and/or broadened photopeaks regardless of position along the crystal axis where the slices are cut. On the other hand, we have made detectors using over 80% of the total volume of crystals, each one showing excellent charge collection, when the dislocation density was low ($< 10^4$ cm^2) and the distribution is homogeneous.

In Fig. 1 the correlation between dislocation density and spectrometric performance of 13 planar detectors selected at random from different single crystals is shown. These detectors all had a diffused Li-n$^+$-contact and a palladium Schottky barrier. The average dislocation density ranged from 10^3 to 2×10^4 cm^{-2} and was more or less uniform across each sample. The spectrometer performance was constant up to approximately 10^4 cm^{-2}; at higher dislocation densities the FWHM and in particular the FW1/10M increased rapidly. All these detectors were operated with a voltage in excess of that necessary for total depletion.

EXPERIMENTS

In order to better understand the effect of dislocations on the charge collection performance, we studied a planar detector which showed tailing of the ^{60}Co gamma photopeaks. The dislocation density was generally low except for some well defined areas. In addition, three radial lineages spaced at 120° were present.

Since the contribution of effects of incomplete charge collection to the line broadening is more pronounced at higher energies, we chose electrons from ^{207}Bi source for preliminary tests.* The electrons were collimated by an In-foil to 1×10 mm^2 on the palladium-electrode. Areas with different dislocation density were compared. The results of two typical areas are shown in Fig. 2. The spectra show that the electron peak was only asymmetrical in the region with high dislocation density. Unfortunately, the intense gamma background of the ^{207}Bi source made more accurate measurements impossible.

To reduce the gamma background we prepared a small low-capacity detector with one lineage by cutting a piece approximately 8×12 mm^2 out of the full area detector under investigation. The electrodes were again placed perpendicular to the dislocation lines and to the lineage plane. Figure 3 shows the ^{207}Bi electron spectra, obtained with this detector. Here the gamma background was much lower. It is clearly recognizable that the shape of the electron-peak depends on the applied bias. Even at twice the depletion voltage (i.e. 1000 V), the electron peak has not yet become symmetrical.

To improve the spatial resolution, we scanned the detector with precisely collimated 59.6 keV gamma-rays from a ^{241}Am source. Using a very-low-noise electronic system we expected that the effect of local inhomogenities on charge collection would be visible at such low energies. Figure 4 shows the etch pattern of the detector surface. The lineage is clearly recognizable as going from low dislocation density ($\sim 2 \times 10^1$ cm^{-3}) to higher dislocation density areas ($> 10^4$ cm^{-2}) towards the edge. The marks at the side

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* Supported in part by the Bundesministerium fuer Forschung und Technologie of the Federal Republic of Germany, and in part by the United States Energy Research and Development Administration.

* Scanning the detector with collimated gamma-rays from ^{60}Co source gives misleading results because many gammas become defocussed by Compton Scattering.

show where the detector was scanned. A beam with a cross section of 0.5 mm^2 was moved across the lineage perpendicular to the Pd-contact.

Figure 5 shows the resultant topography of the peak maximum. Scanning across the lineage revealed a remarkable decrease in the peak height. Scans 1 and 2 were in part influenced by surface effects, but even here the decrease in peak height in the lineage area can clearly be seen. Near the end of the lineage the peak height reaches its maximum value across most of the width of the detector.

Strauss[2] found a similar photopeak decline when irradiating the i-zone of a coaxial lithium drifted Ge detector in areas of higher dislocation density. In his experiment, however, the influence of a surface channel cannot be neglected. This restriction does not apply to our experiments.

Figure 6 shows the ^{241}Am spectra taken in and near the lineage region. The distance between two irradiated points is 0.5 mm. Close examination of the peak shapes shows that the collection efficiency stays nearly constant. The reduction of the peak height is only revealed by the low-energy tailing. The high-energy resolution of our system made it possible to recognize this small change. The FWHM increased from 0.8 keV outside to 0.9 keV inside the lineage region.

These local high-resolution experiments show that dislocations can change the performance of high-purity Ge detectors. When one scans the palladium-side with low-energy gamma-rays the carrier collection is determined mainly by the electrons. Low-energy tailing in the spectra, therefore, results from incomplete electron collection. Scanning with the beam parallel to the electrodes across the depleted region from the Pd- to the n^+-contact confirmed the above results. The low-energy 'tails' of gamma-ray photopeaks are generally ascribed to trapping or field inhomogenities in a detector. However, only qualitative statements can be made regarding which of these mechanisms could be produced by lattice defects in particular dislocations.

QUALITATIVE THEORETICAL MODEL

There exist several models which correlate the shapes of gamma-peaks with trapping centers in the depletion region of a detector. These models are based on homogeneous distribution of traps, constant cross section and/or homogeneous gamma absorption.[3-6] In the case of dislocations, all of these conditions are strongly violated, therefore we had to restrict ourselves to understanding the basic mechanism of incomplete charge collection in the presence of dislocations.

Read[7] described the electronic structure of dislocations with the 'dangling bond' model. Dislocations are rows of atoms with broken bonds which can accept further electrons. It is generally assumed that the acceptor centers lie in the upper half of the forbidden band at around E_C - 200 meV.[7,8] In more recent work Labusch[9] proposes two bands around E_C - 100 meV and E_V + 100 meV. In contrast to levels created by chemical impurities, the levels formed by dislocations are not fixed at a certain energy in the forbidden band. The levels change their positions depending on the value of the 'filling factor' which indicates how many broken bonds have accepted an electron.

Depending on the position of the Fermi-level we can describe two extreme cases:

1. The Fermi-level lies above the dislocation acceptor levels or bands, as is the case in n-type material. This means that the acceptors are occupied with electrons. The row of negative charges will create a cylindrical space charge region often referred as 'space charge pipe'.
2. The Fermi-level lies below the dislocation acceptor levels or bands (p-type material). In this case the levels are empty (i.e. neutral).

Neither of the two cases can be directly applied to a reversed biased pn-junction at 77 K. A good assumption is that the various donor and acceptor levels are occupied as if the Fermi-level would lie in the middle of the gap. In this case the dislocation acceptors are empty most of the time, indicating that they are effective electron traps. The measurements with collimated ^{241}Am gamma-rays confirm this assumption.

In the case of agglomeration of dislocations to lineages the situation gets more complicated. The material becomes locally extremely disordered and can strongly distrub the electric field distribution in the pn-junction.

CONCLUSIONS

As a general conclusion we have to state that the electrical behavior of dislocation as predicted by the dislocation models is not yet well understood or experimentally supported. Much more detailed studies have to be carried out before one can understand the incomplete charge collection due to dislocations. We have shown that dislocations strongly affect the detector properties and that electron trapping is predominant in high-dislocated material.

ACKNOWLEDGEMENTS

We would like to thank F. S. Goulding for his continuous interest in our work and the contribution of many original ideas. R. H. Pehl and R. C. Cordi helped in the selection of the high-purity Ge detectors and in setting up the high-resolution and scanning systems. W. L. Hansen grew all the high-purity Ge crystals used in these investigations. And thanks also go to R. Berger for his help in clarifying some of the theoretical questions.

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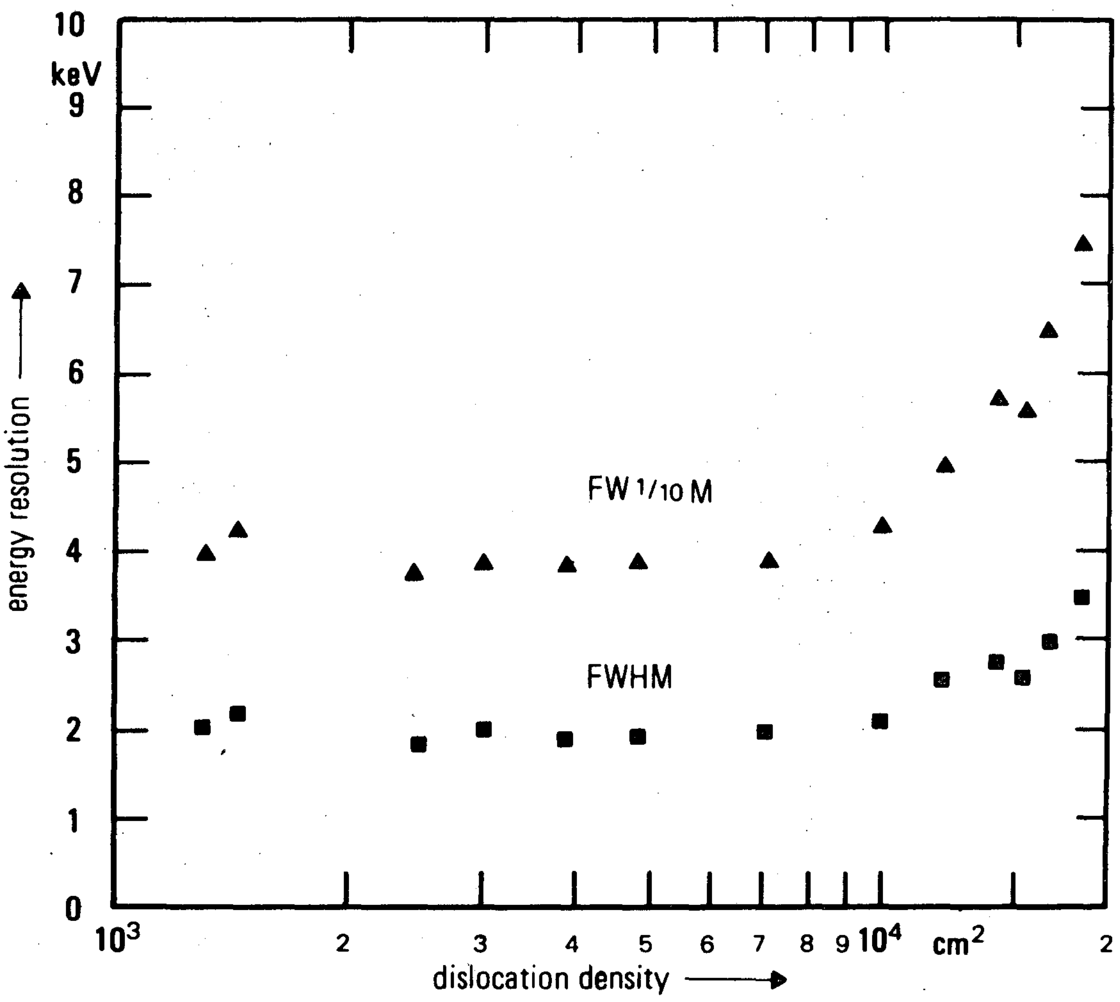
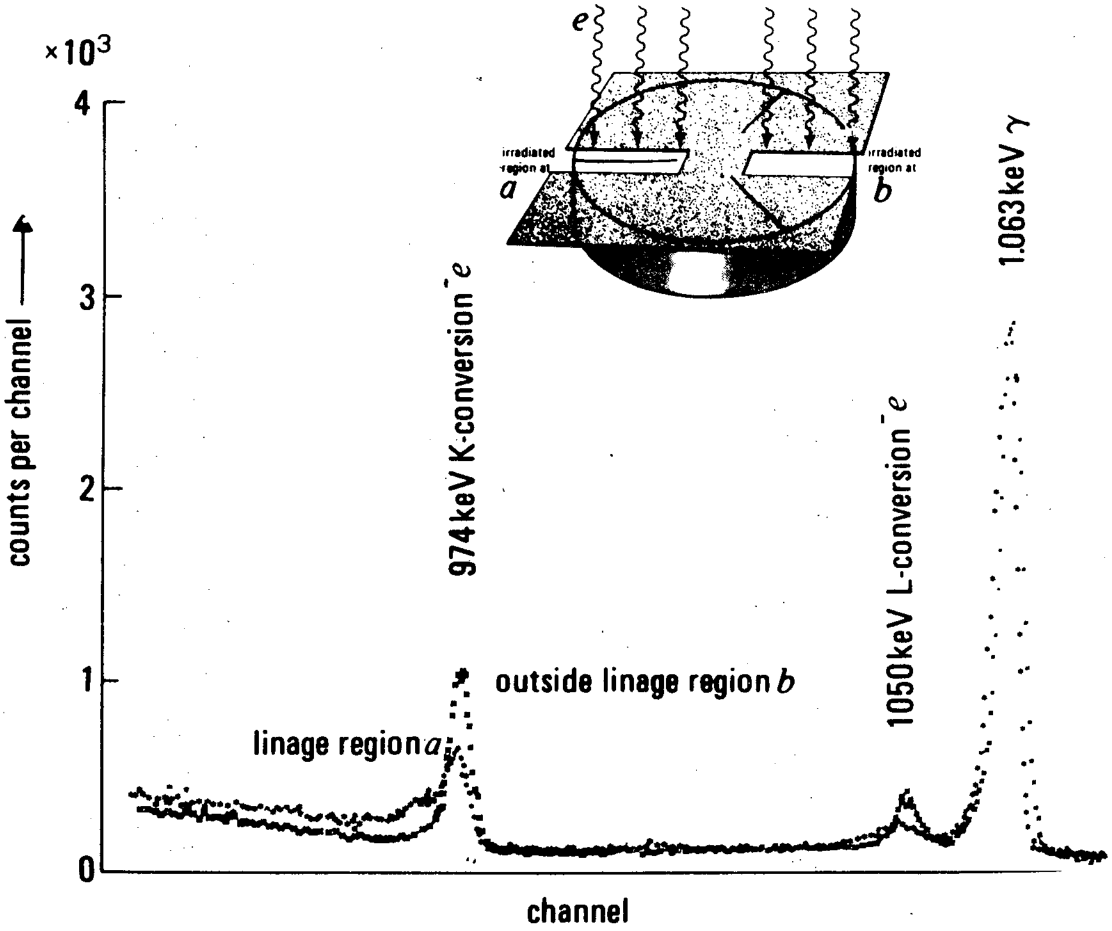


Correlation between dislocation density and energy resolution shown by 1.33 MeV γ-irradiation of Co 60 of 13 planar high-purity germanium detectors. Detector area: approx. 10cm^2; Depletion width: 1cm

XBL 7511-9605

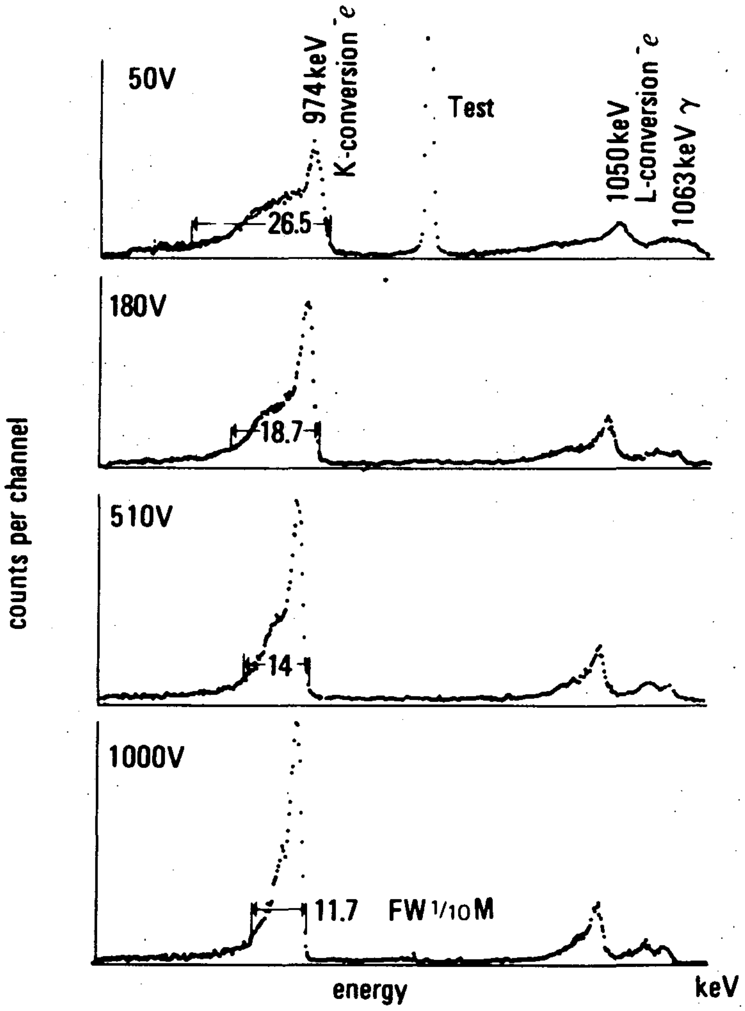
Figure 1



Spectra of γ-rays and conversion- electrons from ^{207}Bi of Detector No.297/2 in and outside the lineage region

XBL 7511-9607

Figure 2



Spectra of γ-rays and conversion-electrons from ^{207}Bi of the small detector 297/2a at various voltages

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Figure 3

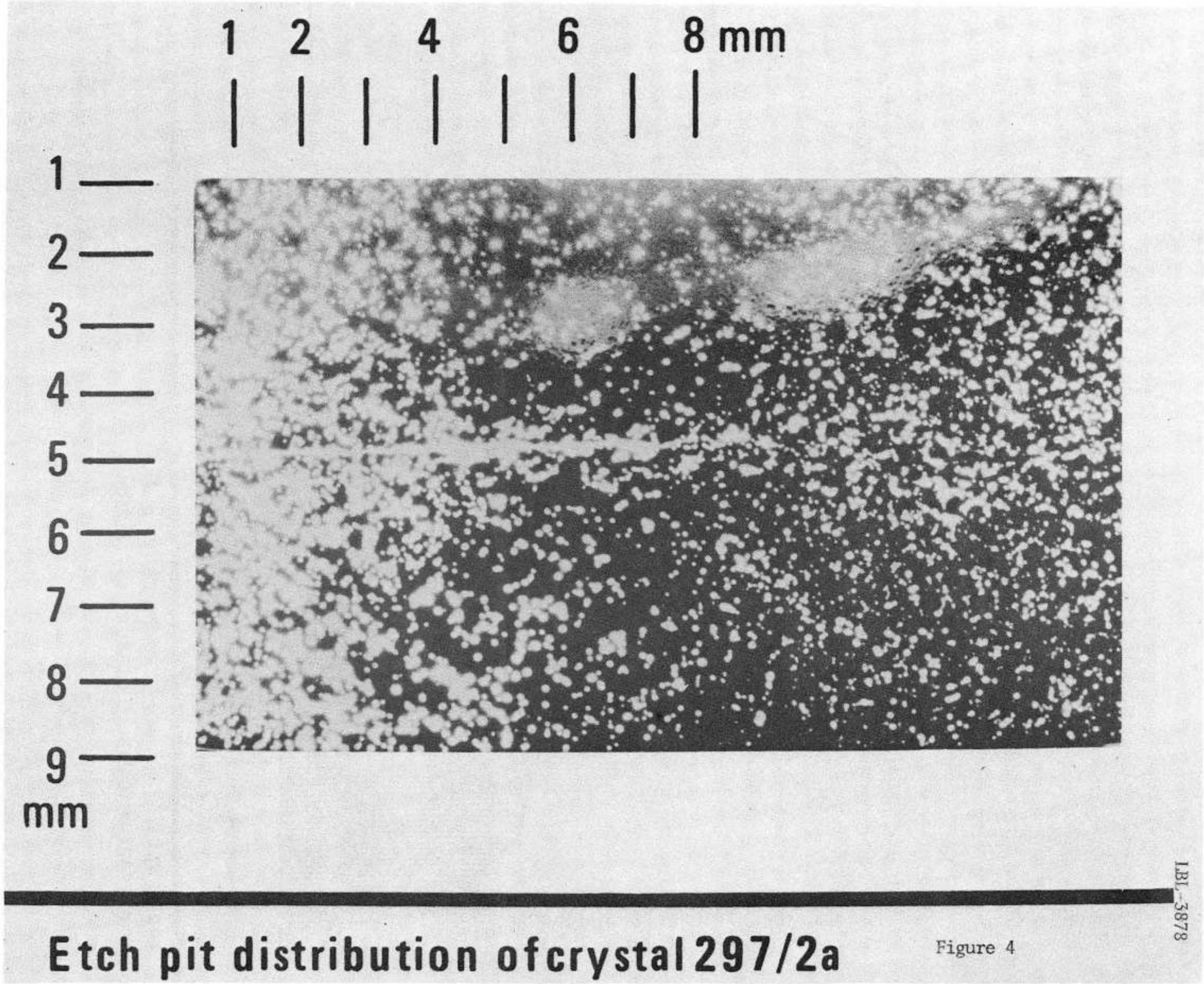

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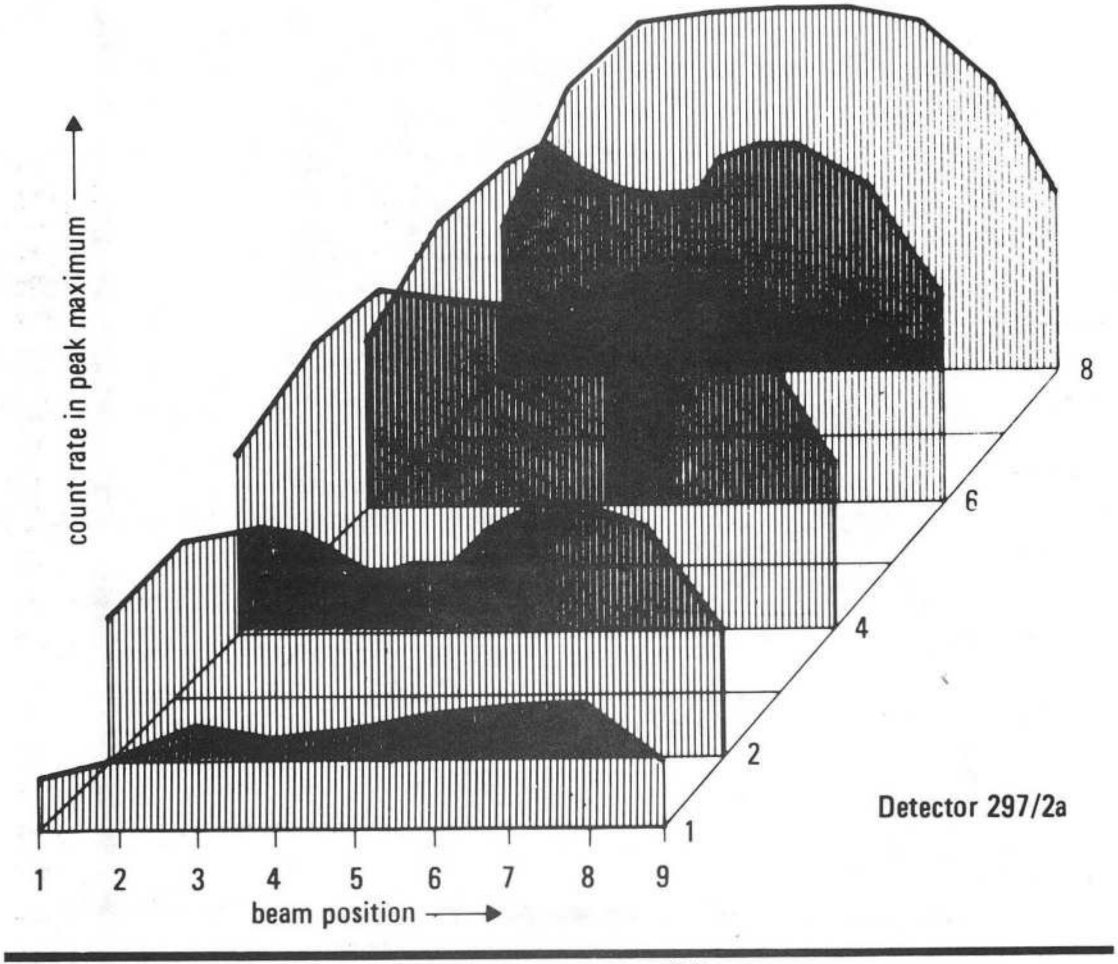
Figure 4



Topography of the peak maximum of 59.6 keV ^{241}Am γ-rays
Four scans with 1 mmϕ beam across lineage

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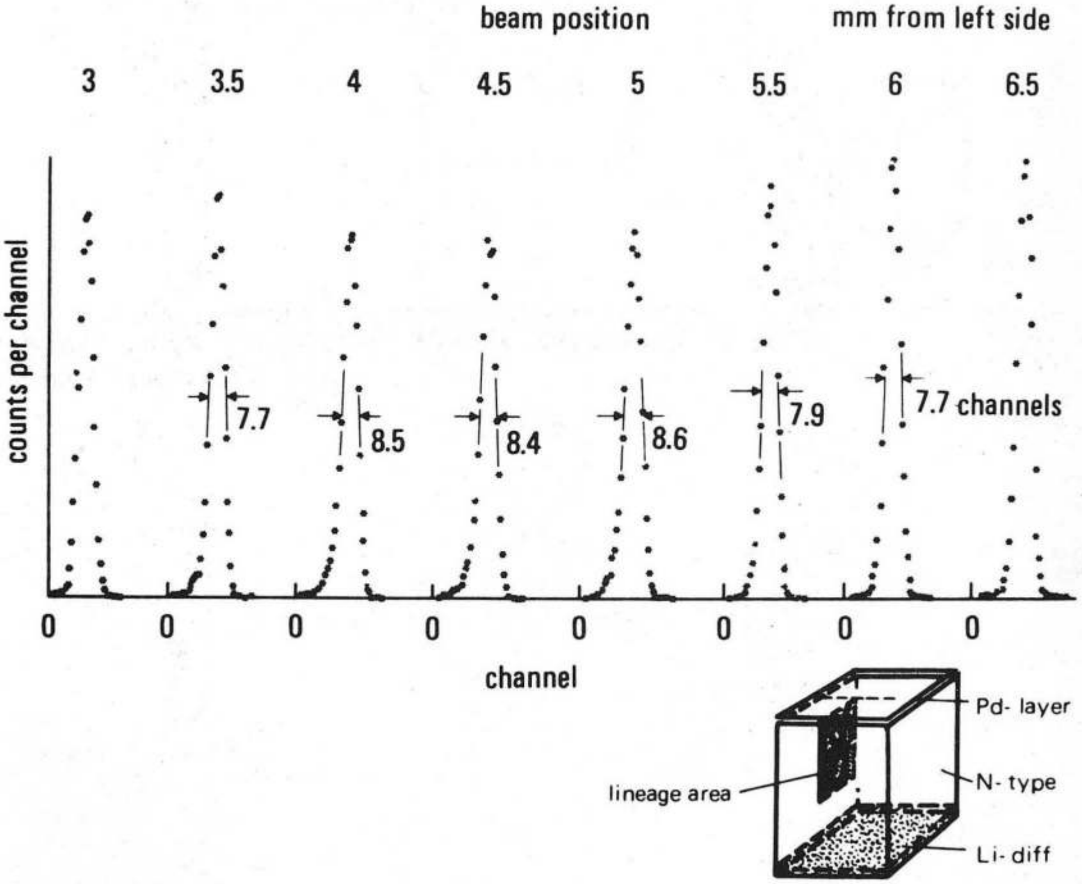
Figure 5



Scan across a lineage of No.297/2a with a 1mmϕ beam of 59.6 keV^{241}Am γ-rays

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Figure 6

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