MÖSSBAUER STUDY OF 57Co IMPLANTED IN SILICON AND GERMANIUM

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Institut voor Kern- en Stralingsfysika, University of Leuven, Physics Department, 3030 Leuven, Belgium

Résumé.- Des expériences dans des grands champs externes montrent que le doublet observé dans les spectres Mössbauer du ^{57}Fe dans Si et Ge, produit par implantation d'ions à une dose de 10^{14} ou plus, est dû à l'interaction quadrupolaire. Dans les doses d'implantation plus faibles on remarque une nette dépendance de cette dose. Des effets prononcés d'annihilation thermique seront discutés.

Abstract.- Experiments in large external fields show that the doublet observed in the Mössbauer spectra of ^{57}Fe in Si and Ge, obtained by ion implantation to a dose of 10^{14} or higher is due to quadrupole interaction. At lower implantation doses a remarkable dose dependence was observed. Some pronounced thermal annealing effects will also be discussed.

1. Introduction.- The Mössbauer spectrum of implanted ^{57}Co and ^{57}Fe in Si and Ge has been investigated since long /1-3/. Conflicting theories have been used to account for the observed spectra. One of the main points of discussion is the origin of the doublet observed in the Mössbauer spectra of ^{57}Fe in Si (figure 1) and Ge. While some authors favor the two single lines hypothesis /1-2/, others tend to believe this is a quadrupole doublet /3/.

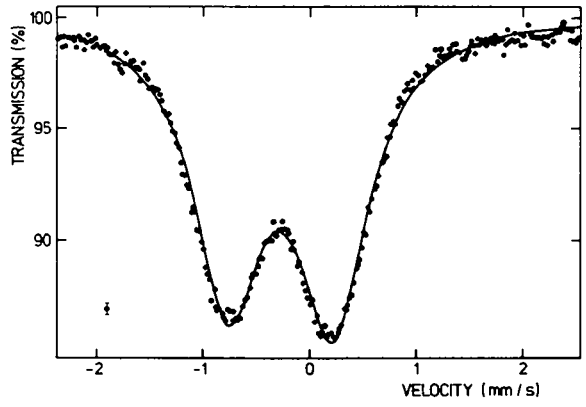

Fig. 1 : Mössbauer spectrum of ^{57}Co implanted in Si to a dose of 10^{14} atoms/cm^2.

Part of this study is devoted to an experiment to solve this controversy. During these experiments a remarkable dose dependence was observed, and very pronounced annealing effects were found to be present. Therefore a more extensive study on these phenomena was undertaken. A detailed account of these experiments will be given elsewhere, but a brief survey of the observed effects will be given at the end of this paper.

2. Experimental.- Sources were prepared by ion implantation at room temperature of ^{57}Co into Si and Ge single crystals with an energy of 70 keV and a dose ranging from 10^{12} to 10^{14} atoms/cm^2. An enriched potassium ferrocyanide absorber of 0.5 mg/cm^2 ^{57}Fe was used. The thermal annealing of some samples was performed under a flowing argon atmosphere always for a period of three hours.

3. Measurements in external field.-Figure 1 shows the spectrum of a source of ^{57}Co in Si, with an implantation dose of 10^{14} atoms/cm^2. This is an almost symmetric doublet with lines at -0.78(3) mm/s and +0.21(3) mm/s. The application of an external field to this source should change the spectrum in such a way that clearly can be distinguished whether these are two single lines or a quadrupole doublet. Measurements were performed in an external field of 80 kG applied to this source, and to a similar source of ^{57}Co in Ge, as we described in detail in a recent paper /4/. The best fit to the spectrum in an external field was clearly obtained with the quadrupole interaction hypothesis, as can be seen in figure 2 for the case of Si. The dashed line in this figure is a theoretical calculation considering these lines as two single lines, both split by the external field, while the full line is a fit with a combined magnetic plus quadrupole interaction considering the two lines as the members of a quadrupole doublet.

Independently a similar conclusion was reached by Sawicka et al. /5/ for the spectrum of stable ^{57}Fe,

*Aangesteld Navorser N.F.W.O.

**On leave from the Central Research Institute for Physics, Budapest, Hungary.

implanted in Si to a much higher dose of 10^{16} atoms/cm^2.

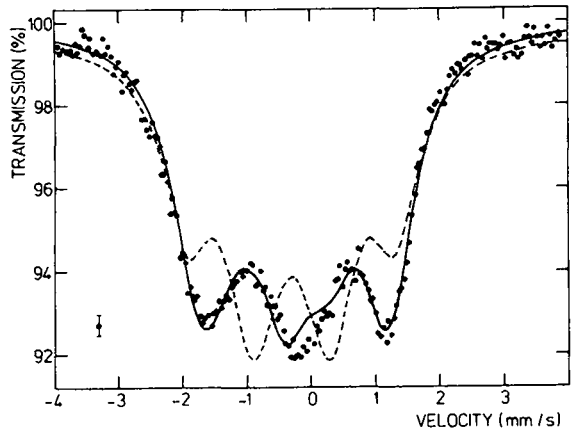

Fig. 2 : Mössbauer spectrum obtained by applying 80 kG to the source used in figure 1. The gamma rays are detected parallel to the field direction.

4. Dose Dependence.- During our experiments we discovered that when a lower implantation dose is used the spectrum shape changes drastically. This is illustrated in figure 3 for sources of ^{57}Co in Ge with implantation doses of 10^{12}, 10^{13} and 10^{14} atoms/cm^2 respectively. A similar behaviour was observed for sources implanted into Si. In addition to the quadrupole doublet a substantial single line fraction is present in the Mössbauer spectrum.

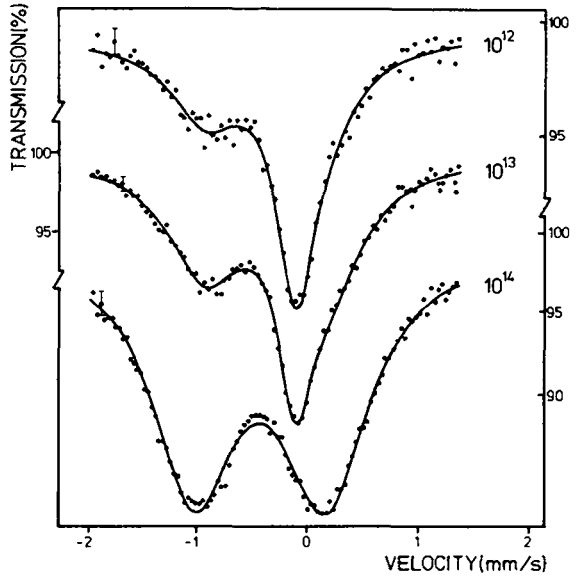

Fig. 3 : Mössbauer spectrum of ^{57}Co implanted in Ge with several implantation doses.

Such a behaviour is fairly unexpected as it has been shown by Sawicka et al. /3/ that at doses ranging from 5 x 10^{14} atoms/cm^2 to 5 x 10^{16} atoms/cm^2 the spectrum remains a symmetric doublet. The reason for this drastic change in the spectrum has probably to be found in the fact that at these lower doses we are below the amorphisation limit of the crystal. The quadrupole doublet then reflects those Co atoms that are imbedded in an amorphous surrounding. At lower doses, however, a substantial fraction of the implanted atoms have a chance to land in an undamaged region of the crystal, and come to rest in a highly symmetric lattice site, giving rise to the single line in the Mössbauer spectrum.

5. Annealing behaviour.- The annealing behaviour of ^{57}Co sources in Si and Ge turned out to be very complex. Especially in Si, every new Mössbauer spectrum taken after a new annealing step 100°C higher than the previous one turned out to be different. A detailed account of the different observed annealing steps will be given elsewhere. Some major observations were :

- a recrystallisation of the amorphous layer is clearly observed around 200°C and 300°C for Ge and Si respectively. This is seen by a sudden collapse of the quadrupole doublet to less than half of its value.
- at higher annealing temperatures, the behaviour of ^{57}Co in Si and Ge is different.
- in the Ge lattice, the Co atoms remain stabilized in a lattice site characterized by a quadrupole interaction, until they start to diffuse out of the lattice.
- in Si, on the other hand, the spectrum is finally dominated by a single line with the same isomer shift as the one appearing in the lower dose unannealed spectra, so that in Si the Co atoms seem to stabilize in a more symmetric lattice site than in Ge.

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Referehces

/1/ Weyer,G., Grebe,G., Kettschau,A. Deutsch,B.I., Nylandsted Larsen,A. and Holck,O., J.Physique 37 (1976) C6-893.

/2/ Latshaw,G., Ph.D.Thesis, Stanford University (1971).

/3/ Sawicka,B.D., Sawicki,J.A. and Stanek,J., J. Physique 37 (1976) C6-879.

/4/ Langouche,G., Dezsi,I., Van Rossum,M., De bruyn J. and Coussement,R., to be published in Phys. Stat. Sol.

/5/ Sawicka,B.D. and Sawicki,J.A., Phys. Lett. 64A (1977) 311.