Study of neutrino-recoil produced point defects in InSb by $^{119}$Sn Mössbauer spectroscopy

L. Wende, R. Sielemann

HMI Berlin, Glienicker Strasse 100, 14109 Berlin, Germany

and

G. Weyer

University of Aarhus, 8000 Aarhus C, Denmark

We have utilized the electron-capture decay of $^{119}$Te to $^{119}$Sb to produce isolated single Frenkel pairs in InSb. This effect is caused by the neutrino emission in the decay process which imparts a monoenergetic recoil of 12 eV to the $^{119}$Sb atoms, thereby displacing about 20% of them to interstitial sites. Two distinct interstitial components can be observed. The process is traced by Mössbauer emission spectroscopy following the decay of $^{119}$Sb to $^{119}$Sn. The displacement threshold $E_d$ is confined to $6 \text{ eV} < E_d < 12 \text{ eV}$ from auxiliary experiments employing $^{119m}$Te isotopes.

1. Introduction

Nuclear probe methods such as the Mössbauer effect and perturbed angular correlations (PAC) have increasingly been utilized to study defect properties in semiconductors [1,2]. These methods use radioactive probe atoms which by way of the nuclear hyperfine interaction are sensitive to their immediate environment. In this way information on the probe’s lattice position and closely associated defects can be obtained. In principle, the hyperfine interaction contains information on the geometric as well as electronic structure. In addition, the local lattice dynamics as well as migration kinetics of the probes and the defects can be studied. The application of the probe methods to intrinsic defects, however, has remained difficult due to the basic problem of a proper defect identification.

In the present paper we will report on experiments solving this problem by correlating the production of Frenkel pairs close to the displacement threshold with the Mössbauer effect as the analyzing technique. The idea of these experiments is as follows: We employ the Mössbauer probe $^{119}$Sn which is normally populated in the electron capture decay (EC) of $^{119}$Sb. In our experiment, however, we start with the
radioactive precursor $^{119}$Te in its ground state, $^{119}$Te, leading to the decay chain (fig. 1):

$$^{119}$Te(16 h) $\overset{\text{EC}}{\rightarrow}$ $^{119}$Sb(38 h) $\overset{\text{EC}}{\rightarrow}$ $^{119}$Sn. \hspace{1cm} (1)$$

The neutrino emitted in the first EC decay leads to a recoil energy

$$E_R \equiv Q^2/2M c^2 = 12 \text{ eV}.$$ \hspace{1cm} (2)

$Q/c^2$ is the mass difference between $^{119}$Te and $^{119}$Sb while $M$ denotes the mass of $^{119}$Sb. We use this recoil process to produce Frenkel pairs spatially correlated to the $^{119}$Sb probe in otherwise undamaged InSb. In this compound semiconductor the threshold for Frenkel pair production is known to be about 6–10 eV [3]. In the final decay $^{119}$Sb $\rightarrow^{119}$Sn, the "proper" Mössbauer decay, only 1.3 eV recoil energy is freed (also due to neutrino emission), which is too small to cause defects. Therefore the Mössbauer measurement on $^{119}$Sn is a true "analyzer" of the preceding recoil process, which in effect makes the Mössbauer probe the primary knock-on atom (PKA) in the defect production.

To check for the possibility that the chemical nature of the Te probes might give rise to Mössbauer lines other than the substitutional line even without a recoil effect, a second type of experiment is performed in which we start with the radioactive $^{119}$Te in its metastable state, $^{119m}$Te: