



Characterisation of 60° misfit dislocations in SiGe alloy using nuclear microscopy

L. Huang^{*}, M.B.H. Breese, E.J. Teo

Department of Physics, 2 Science Drive 3, National University of Singapore, Singapore 117542, Singapore

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Abstract

This paper uses the transmission ion channeling technique on the NUS Singletron accelerator to map misfit dislocations at the interface of a SiGe layer epitaxially grown on a (001) silicon substrate. A bunch of five 60° dislocations and a single dislocation have been studied using a focused 2 MeV proton beam with a spatial resolution of 60 nm and good image statistics. The bent (110) planes due to 60° dislocations cause the image contrast to change asymmetrically while tilting the sample close to the channeling direction.

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1. Introduction

Transmission ion channeling uses a focused MeV ion beam to generate images showing variations in crystal quality along a specific crystal direction [1,2]. High-energy ions follow a channeling process when aligned with a crystal orientation, in which they are steered by the rows and planes of the lattice, so that they travel in regions of lower atomic electron density, and their energy

loss rate is therefore reduced. If crystal defects distort the lattice planes, this can produce abrupt changes in the channeling direction, so the originally channeled ions become dechanneled with the higher energy loss rate.

A SiGe alloy has a larger lattice parameter than pure silicon owing to the different lattice parameters of Si and Ge [3]. If a thin layer of SiGe is grown onto a Si substrate, above a certain layer thickness, the strain in the layer is relieved by the formation of misfit dislocations, which are usually 60° dislocations. 60° dislocations locally bend the (110) lattice planes and cause the channeled ions

^{*} Corresponding author.

E-mail address: scip1308@nus.edu.sg (L. Huang).

to be dechanneled. Therefore, ions passing through the sample with different energies can be measured and images of interested region can be produced.

In this paper, a focused 2 MeV proton beam, generated by a Singletron accelerator [4], has been used to scan the surface of an etched SiGe sample which was thinned about 20 μm thick. Images of a bunch of five 60° dislocations were recorded. Moreover, line scans were applied across this bunch of dislocations to clearly measure the asymmetrical changes of contrast caused by the 60° dislocations while tilting the sample close to the (110) planar direction.

2. Experimental procedures

Protons transmitted through a thinned SiGe sample with a 2 MeV proton beam scanning the sample surface were detected by an ORTEC ULTRA alpha detector, with a Mylar foil placed in front of it (see Fig. 1). The voltage-pulse output of the detector is amplified by a CANBERRA 2004DM and 2015A amplifiers before being fed into the data acquisition system (OMDAQ). The image is displayed with a pixel resolution of 256×256 . In order to improve the data statistics, a longer data acquisition time was selected.

The SiGe sample was mounted on a small, motor-driven rotating stage, which can rotate around the horizontal axis at a small angle of about $0.5^\circ/\text{step}$. As a result, relevant regions of

the sample can be easily reached by the 1-axis rotation stage and 3-axis translation stage.

Owing to the restricted chamber geometry without a goniometer to mechanically tilt the sample, small angular changes were made in the beam alignment by shifting the location of the collimation slits of the nuclear microprobe away from the beam axis. A vertical collimator displacement of 25 μm produced a change of 0.02° in the beam alignment with respect to the horizontally-running (110) planes, comparable to the planar channeling critical angle of Si at 2 MeV protons, $\Psi_p = 0.17^\circ$, and caused no detectable loss of spatial resolution using a beam spot size of 60 nm.

The function of the Mylar foil (see Fig. 1) used here is to block the transmitted protons with energy lower than the pre-set energy value corresponding to the thickness of the Mylar foil. Therefore, by selecting the thickness of the Mylar foil the desired energy threshold of transmitted protons can be chosen. This means that the Mylar energy loss foil stops most non-channeled protons, so that mostly only channeled protons with higher energy are transmitted [5]. Therefore, the lower energy part of the transmitted energy spectrum, which conveys little useful information is not recorded, and only the useful high-energy protons are recorded. As a result, the signal to noise ratio of images is improved, enabling small contrast changes in the images to be resolved. In this paper, the images were taken with the Mylar energy loss foil of 48 μm thickness.

3. Results

A Nomarski image of a portion of the SiGe sample is shown in Fig. 2. A $[110]$ 60° dislocation cross-arm is seen here, and since a low magnification was used for taking this image, etch pits caused by threading dislocations cannot be seen along the dislocation arms. Fig. 3 shows a transmission channeling image of the same region of the sample with the scan size of $220 \times 66 \mu\text{m}^2$, recorded for 38 min. The thinned sample was bent locally owing to the strain in the epilayer. Therefore, the background of the image becomes progressively darker from right to left. Since the

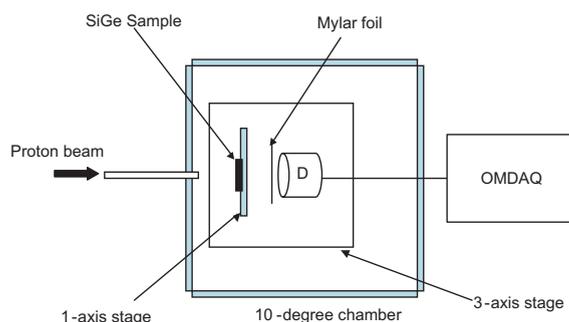


Fig. 1. A schematic of the experimental set-up.

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