

## The influence of nitrogen on dislocation locking in float-zone silicon

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**Abstract.** Dislocation locking by nitrogen impurities has been investigated in float-zone silicon with nitrogen concentrations of  $2.2 \times 10^{15} \text{cm}^{-3}$  and  $3 \times 10^{14} \text{cm}^{-3}$ . The stress required to unlock dislocations pinned by nitrogen impurities was measured as a function of annealing time (0 to 2500 hours) and temperature (550 to 830°C). For all conditions investigated the locking effect was found to increase linearly with annealing time before saturating. It is assumed that the rate of increase of unlocking stress with annealing time is a measure of transport of nitrogen to the dislocation core. This rate of increase was found to depend linearly on nitrogen concentration, which is consistent with transport by a dimeric species, whose activation energy for diffusion is approximately 1.4eV. The saturation unlocking stress has been found to be dependent on the nitrogen concentration. Additionally, the temperature dependence of the stress required to move dislocations immobilised by nitrogen impurities has been studied. By assuming a value for the binding energy of the nitrogen to the dislocation, the density of the locking species at the dislocation core has been calculated.

### Introduction

Silicon manufacturers have recently become interested in intentionally adding nitrogen to silicon as it can allow flexibility in controlling oxygen precipitation [1-4], control vacancy concentration [5] and improve mechanical strength by immobilising dislocations [6]. For these effects to be fully exploited a better understanding of the fundamental properties of nitrogen in silicon is necessary.

It has been established that the predominant nitrogen species at room temperature is the dimer [7] and it has been shown that this is an interstitial defect [8]. Numerical simulations suggest that the nitrogen dimer in silicon is stable up to temperatures of at least 900°C [8] and the binding energy of its two constituent nitrogen atoms is very large (3.67eV) [9]. Simulations also suggest that the activation energy for nitrogen dimer diffusion is also large (at least 3.1eV) [10], implying that nitrogen transport in silicon occurs by a different species or via a complicated mechanism, such as the recently proposed dissociative mechanism [11]. Experimental investigations using SIMS [12] are made difficult because of the technique's lack of sensitivity to nitrogen, and so experimental studies of the transport of nitrogen in silicon are very limited to date.

Dislocations in crystals subjected to annealing can be pinned by impurity atoms and the critical shear stress necessary for movement of these locked dislocations is known as the *unlocking stress*. By studying the variation of dislocation locking as a function of annealing time, it is possible to deduce information on impurity diffusion and impurity-dislocation interactions. A dislocation locking technique has been used to study oxygen in Czochralski silicon (Cz-Si) and at high temperatures [13] reproduced established values of oxygen diffusivity, while at lower temperatures [14], where most conventional techniques are unsuitable, it provided evidence for so-called enhanced oxygen diffusion due to dimers.

Nitrogen impurities have long been known to provide a significant locking effect on dislocations [6]. In this work, the dislocation locking technique used to study oxygen is applied to