PHONON SCATTERING OF OXYGEN-RELATED DEFECTS IN ANNEALED SILICON CRYSTALS

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Oxygen precipitation in Czochralski- (Cz-) silicon with oxygen concentrations around 10^{18} cm^{-3} has attracted much attention during the past decades mainly because of its technical importance. There is still a demand of non-destructive investigation tools which are sensitive to small, i. e. nm-sized oxygen clusters. We have used energy- and time-resolved phonon spectroscopy with superconducting tunnelling junctions to study the scattering of acoustic phonons at these extended defects in the energy range of ≈ 0.3 meV up to 10 meV, corresponding to transverse wavelengths from ≈ 100 nm down to 2 nm (e. g. [Zel99] and references therein). To correlate the observed phonon scattering to the oxygen precipitates we have also investigated their infrared absorption. This paper presents new experiments which clarify open questions of the older studies. The results can be divided into two categories:

1. Although the phonon scattering after annealing at temperatures from 650° up to 1220° always extends over a broad energy range, there are marked differences when carbon-rich ([C] $> 10^{17}$ cm^{-3}) samples are annealed at medium temperatures ($\approx 750°$). Only in this case do combined transmission and backscattering measurements clearly show resonant phonon scattering in the accessible energy range with a maximum at about 2 meV. Since it is known that carbon atoms provide nucleation sites for oxygen agglomeration, leading to the formation of spherical precipitates with diameters of less than 10 nm, we expect that the observed broad resonance is caused by the excitation of vibrational eigenmodes of these spheres. This interpretation is further supported by pulse measurements with superconducting tin tunnelling junctions as phonon generators and detectors showing that at 1.2 meV transverse phonons are stronger scattered than longitudinal phonons as it is expected for geometric scattering. In carbon-lean crystals or at higher temperatures larger precipitates as well as secondary defects such as extrinsic stacking faults or dislocation loops are formed which scatter the phonons non-resonantly over the entire energy range.

2. Around 1050° defects form which cause at least four rather narrow (≈ 0.5 meV) phonon resonances at energies ≥ 2.8 meV [Zel99]. The positions of these lines depend on the annealing time and at least one of them depends sensitively on uniaxial stress. The defects also form in oxygen-lean Float-Zone silicon by indiffusion of oxygen in an oxidizing atmosphere, which unambigously shows that they are some kind of oxygen defect. The nature of the underlying excitation is still unclear, but the defects might be related to deep centers which form under the same annealings as is demonstrated by resistivity measurements.

[Zel99] F. Zeller, K. Laßmann, W. Eisenmenger, Physica B **263 & 264**, 108 (1999)