Ultrasonic Investigation of Ground State of Vacancy Orbital in Boron-Doped Silicon

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We have made low-temperature ultrasonic measurements on elastic constants of boron-doped silicon single crystals grown by a floating zone (FZ) method in order to study the ground state of a vacancy orbital. Although the silicon single crystal is considered to be one of the most pure and ideal crystals, there exist two native point defects of a vacancy and silicon-interstitial. In particular, the vacancy plays important roles for dopant diffusion, oxygen precipitate in silicon wafers used for electronic device fabrications. The elastic constants C_{11}, C_{44}, $(C_{11} - C_{12})/2$ and $C_{L[111]}$ of the boron-doped FZ silicon show a softening with decreasing temperature below 20 K down to 20 mK in zero field. The elastic softening is suppressed with increasing applied magnetic field of up to 10 T and shows anisotropic behavior depending on the field directions. The softening and magnetic field dependence of the elastic constants of the boron-doped silicon are well described in terms of electric quadrupole susceptibility for the vacancy orbital with a Γ_8 quartet ground state in a charge state V^+ accommodating three electrons.