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Theory of spin-dependent phonon-assisted optical transitions in Si and quantifying spin polarization in Si[1]

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The spin polarization of conduction electrons in a direct-gap semiconductor is readily quantified by measuring the circular polarization of the recombination light luminescence. However, in silicon, owing to its indirect band-gap, such a direct connection between spin polarization and luminescence has been conspicuously absent. This missing link is established with a theory that provides concise relations between the degrees of spin polarization and measured circular polarization for each of the dominant phonon-assisted optical transitions [1]. This theory has two important applications. First, it allows one to determine in a parameter-free manner the spin polarization of electrons from the measured circular polarization of the luminescence. Second, it provides a means to extract the spin relaxation time or the spin injection efficiency across ferromagnet/silicon interfaces. In the first part of the talk, by invoking symmetry arguments, I will derive concise optical selection rules for each of the phonon-assisted optical transitions in unstrained bulk silicon. It will be shown that phonon symmetries play a key role in determining the circular polarization degrees of the various phonon-assisted luminescence peaks. In the second part, the optical selection rules will be used to analyze the polarized luminescence spectrum that is calculated by a comprehensive rigid-ion model for doped silicon. The analysis is used to elucidate results of recent spin injection experiments in silicon [2]. The effect of the (weak) spin-orbit coupling in silicon on the luminescence turns out to be unique due to the proximity of the split-off band to the heavy and light hole bands in unstrained bulk silicon (44 meV). This proximity gives rise to a fast reduction in the circular polarization degree of the luminescence in p- type silicon.

[1] P. Li and H. Dery, Phys. Rev. Lett. 105, 037204 (2010).
[2] B. T. Jonker et al., Nature Phys. 3, 542 (2007).

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