Optical Spin Pumping in Silicon

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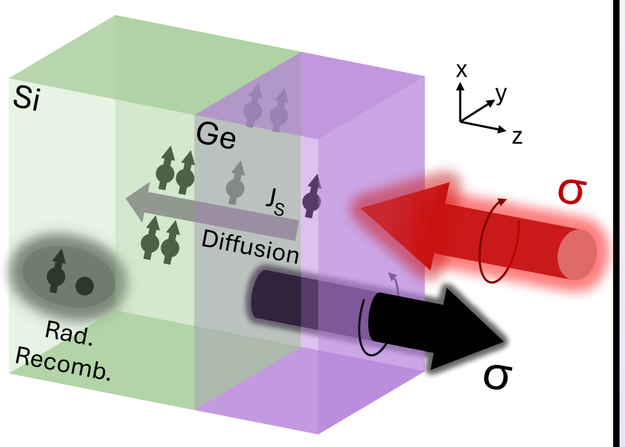
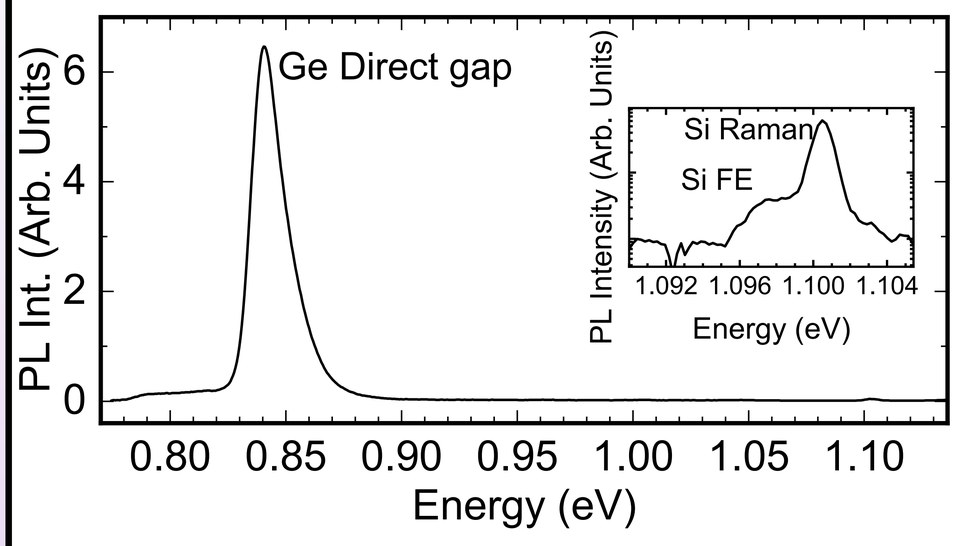
Optical spin orientation is a light-matter interaction process that allows the generation of an out-of-equilibrium spin population. This process consists in the excitation of a semiconductor material with circular polarized light [1]. Here, we report a modified approach in which spin polarized carriers are at first injected into an absorbing film and then transferred to an adjacent indirect band gap semiconductor. We apply this optical scheme to silicon demonstrating spin polarized emission from it. So, we improve the inefficiency of Si due to the indirect gap and the complete relaxation of the spin from a very high direct gap. This approach unlocks the optical exploitation of Si's spin-dependent phenomena previously hindered by its indirect electronic structure.

Optical Spin Pumping Effect

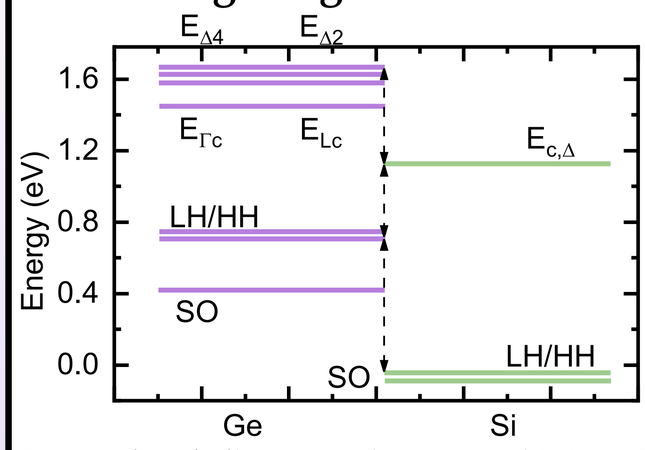


Ge acts as spin injector under optical excitation with **circularly polarized light**. **Si** functions as a spin sink and **emits polarized luminescence**.

Photoluminescence spectrum of the Ge/Si heterostructure

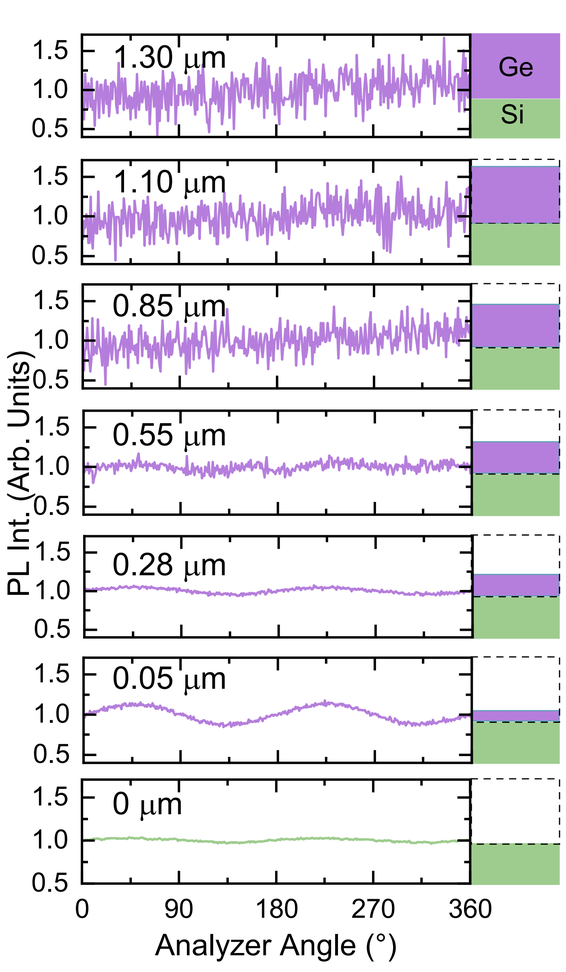


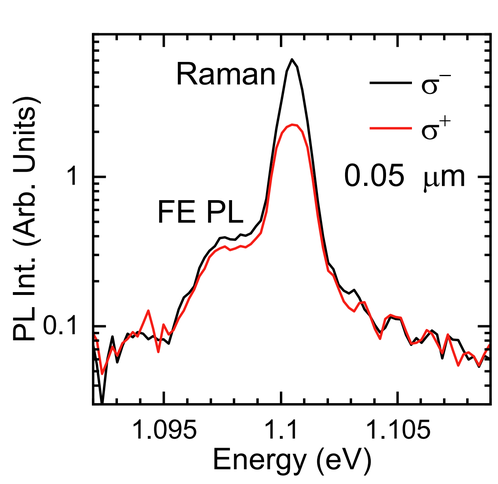
Valence and Conduction band edge alignments

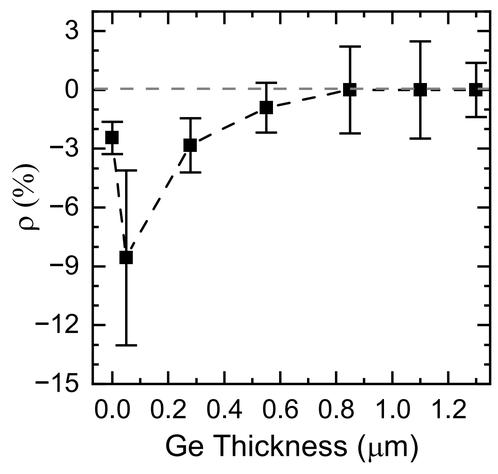


Type II band alignments between cubic Si and tensile-strained Ge [2], where **spin polarized e⁻** start from **Ge** and end into **Si** .

Observation of polarized emission from Si



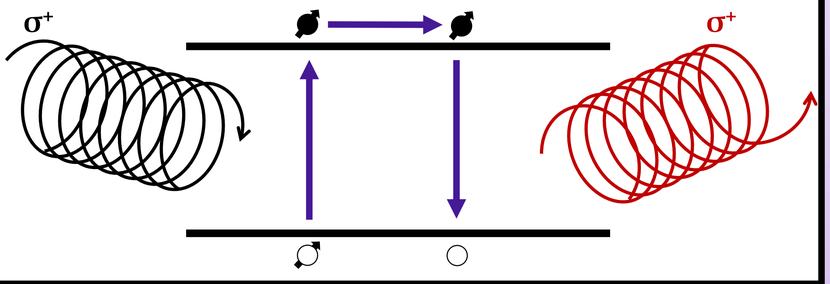




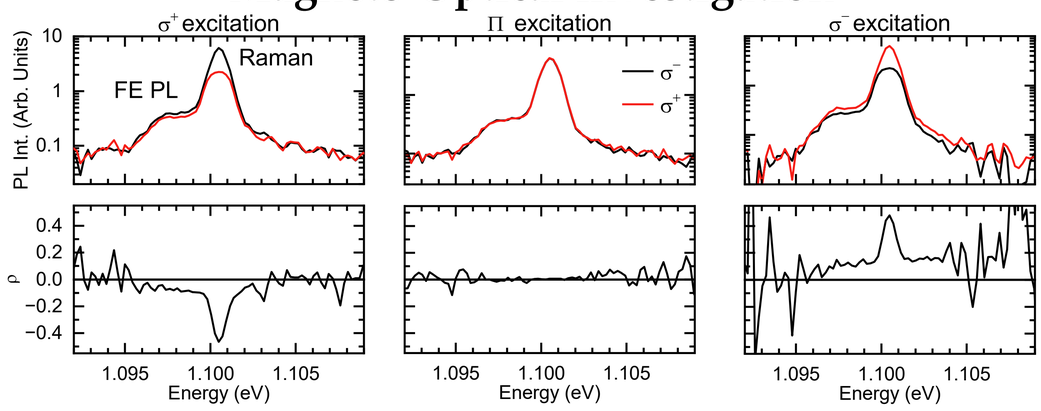
- **Polarization** analysis of the **Si FE PL** at 1.097 eV performed at T=4 K.
- The investigation is performed for **various Ge thicknesses** by chemically etching the Ge film from 1.3 μm down to 0 μm.
- **Polarization degree** increases until it reaches a maximum value of **~ 9%** .

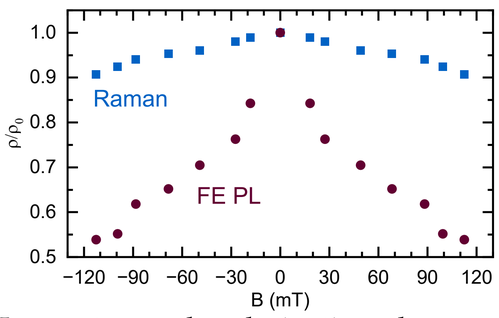
Optical Orientation

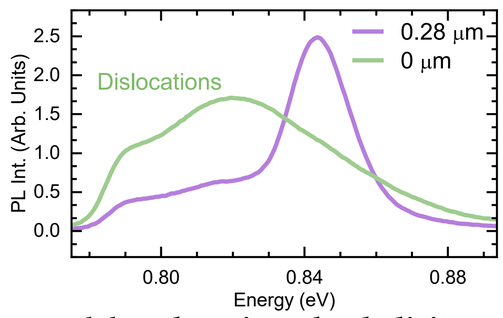
Transfer and **conservation of angular momentum** ($\Delta m=\pm 1$) from light [3].



Magneto-Optical investigation







- PL spectra and polarization degree measured by **changing the helicity** of the incident light, **evidences of spin-related emission**.
- Polarization degree as a function of a transverse magnetic field (**Hanle effect**) confirms the spin dependent origins and suggests a **short spin lifetime of Si** (~200 ps). This short time is due to **extended defects** [4].

Conclusions

- We demonstrated the **Optical Spin Pumping process** and its practical application.
- **Record polarized emission** in Si (~ 9%), overcoming problems caused by indirect band gap.

References

[1] G. Lampel, Phys. Rev. Lett. 20, 491 (1968).
[2] C. G. Van de Walle and R. M. Martin, Phys. Rev. B 34, 5621 (1986).
[3] E. Vitiello et al. ,Physical Review B 92.20 (2015): 201203.
[4] N. A. Drozdow et al. ,Teor. Fiz 23, 597 (1976).

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Acknowledgements

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