

Surface-mediated electron spin dynamics of Mn deposited GaAs (110) probed by Optical Pump-probe Scanning Tunneling Microscopy

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Semiconductor spin dynamics has always been a research focus both theoretically and experimentally for many decades, as understanding quantum dynamical behaviors of electrons, holes, as well as nuclei in semiconductors are quite essential for further development on Spintronics and quantum computation. Especially for diluted magnetic semiconductors (DMSs), in which some more intriguing spin properties had been discovered compared to non-magnetic semiconductors, are considered to be of high potential in actual Spintronics applications. Here we present a novel STM-based ultrafast measurement technique that our group has originally developed, to investigate spin dynamics of an in-situ UHV cleaved GaAs (110) surface with Manganese (Mn) adatoms. Empowered by this time-resolved ultrafast Optical Pump-probe Scanning Tunneling Microscopy (OPP-STM) technique, we are able to observe surface-impurity-mediated spin dynamics which are influenced by Mn adatoms, at nano-scale, and exclusively with high temporal and spatial resolution at the same time.

Namely, our OPP-STM system combines the well-known Optical Pump-probe (OPP) technique with STM, to dramatically enhance the temporal resolution of STM, while the spatial resolution is hardly being compromised. Simply speaking, laser system is set in a typical time-delayed, optical pump-probe scheme, but with our originally developed laser modulation technique in order to get rid of the tip thermal expansion effect. In our case, both pump and probe laser pulses are modulated in terms of their circularly polarization states using our laser modulation unit (CPLD-based electronics with controlling algorithm), they are focused and guided collinearly to illuminate the tip-sample junction in UHV ($<10^{-8}$ Pa). By making use of the Tip-induced-band-bending (TIBB), as well as light-induced, transient Surface Photo Voltage (SPV) effect, electron spin dynamics can be resolved by measuring the lock-in-detected tunneling current.

In this experiment, we investigated electron spin dynamics in Mn-deposited, n-type GaAs sample at room temperature. Instead of using MBE-grown $\text{Ga}_x\text{Mn}_{1-x}\text{As}$ sample, by evaporating Mn atoms on an UHV cleaved GaAs surface, we are able to control the amount of Mn adatoms on GaAs (110) surface, as well as investigating the spin lifetime dependence in terms of Mn amount. We have observed that the electron spin lifetime of GaAs has a nonlinear behavior with respect to Mn amount, which can be explained by the Dyakonov-Perel spin relaxation mechanism. More interestingly, compared with the conventional OPP method, we have found that our OPP-STM method is far more surface sensitive for probing local spin dynamics. Details of the experimental design as well as experimental results will be introduced in the presentation. Moreover, recent progress on newly developed nuclear-spin-sensitive OPP-STM system, which might be enabling us to probe nuclear spin dynamics on nanoscale, will also be briefly reported.

References:

- [1] T. Dietl, et al. *Nature Materials* 9, 965–974, 2010.
- [2] S. Yoshida, et al. *Nature Nanotechnology* 9, 588-593, 2014.
- [3] *Spin Dynamics in Semiconductors*, Springer, 2008.