Master's Thesis with the WMI and WSI

Are you a master's student looking for a thesis in the **intersection of superconducting and semiconducting** physics? Are you interested in learning from a range of PhD students across two high quality institutions? Do you enjoy **coding**, generating and analysing **simulations**? Consider the following master's thesis proposal:

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The Topic

In classical computing, transduction is used to convert your phone's electric signals into microwaves to reach your WiFi router. Analogously in quantum computing, quantum transduction techniques are essential for quantum networking protocols, utilising flying (photonic) qubits, to exchange information between static (e.g. trapped ion, neutral atom, or superconducting) qubits.

There are many proposals and hardware platforms which are being researched to achieve this. Our approach is to use an InAs quantum dot molecule in a GaAs waveguide to convert optical photons into an exciton, which can decay by emitting a microwave photon into a (closely located) superconducting microwave resonator and a complementary red detuned photon to herald a successful transduction event. The key question is: how do we design the superconducting components and the surface of the waveguide to prioritise this channel of decay?

Your task will be to use Ansys HFSS (or similar) software to investigate the interaction of the electric and magnetic fields of a microwave mode in a superconducting resonator flip chip bonded to an n-doped semiconducting stack, and realise first experimental demonstrations.

- What kind of structures and geometries maximise the electric field of the microwave mode at the site of the quantum dot molecule?
- Is it necessary to coat the semiconducting chip with a superconductor to engineer the local electric field?
- How close can the coating come to the waveguide such that the microwave is not internally reflected?
- How stable is the design to local imperfections in lateral (placement) and vertical (pressure on the flip chip bonded Indium bumps) positioning?

With a range of test designs at hand, you will work with a PhD student in flip chip bonding, and a PhD student in fabricating microwave resonators at the WMI, as well as a PhD student fabricating semiconducting waveguides at the WSI. The main placement will be at the WMI under the supervision of Prof. Stefan Filipp.

Requirements:

We are looking for highly driven and creative individuals with some background in semiconducting and superconducting physics and a strong understanding of electromagnetism, to tackle this steep and fruitful learning curve at pace with the possibility of - at the end of the project - fabricating and measuring your simulated geometry. Some experience in Python and Java coding is preferred. **Specific knowledge is not necessary**, but reading some referenced material is advised.

References:

Examples of Transduction:

Mayor, Felix M., et al. "A two-dimensional optomechanical crystal for quantum transduction." *arXiv preprint arXiv:2406.14484* (2024).

Kumar, Aishwarya, et al. "Quantum-enabled millimetre wave to optical transduction using neutral atoms." *Nature* 615.7953 (2023): 614-619.

Tsuchimoto, Yuta, and Martin Kroner. "Low-loss high-impedance circuit for quantum transduction between optical and microwave photons." *Materials for Quantum Technology* 2.2 (2022): 025001.

Quantum Dot Molecules:

Bopp, Frederik, et al. "Quantum dot molecule devices with optical control of charge status and electronic control of coupling." *Advanced Quantum Technologies* 5.10 (2022): 2200049.

Doty, Matthew F., et al. "Hole-spin mixing in InAs quantum dot molecules." *Physical Review B—Condensed Matter and Materials Physics* 81.3 (2010): 035308.

Stinaff, Eric A., et al. "Optical signatures of coupled quantum dots." *Science* 311.5761 (2006): 636-639.

Kim, Danny, et al. "Ultrafast optical control of entanglement between two quantum-dot spins." *Nature Physics* 7.3 (2011): 223-229.

Microwave Resonators:

Göppl, Martin, et al. "Coplanar waveguide resonators for circuit quantum electrodynamics." *Journal of Applied Physics* 104.11 (2008).

Pozar, David M. "Microwave engineering education: From field theory to circuit theory." *2012 IEEE/MTT-S International Microwave Symposium Digest*. IEEE, 2012.

Zhao, Xinyi, "Design of Microwave Superconducting Resonators for Materials Characterization" (2023). *McKelvey School of Engineering Theses & Dissertations*. 855.

Zmuidzinas, Jonas. "Superconducting microresonators: Physics and applications." *Annu. Rev. Condens. Matter Phys.* 3.1 (2012): 169-214.

Bouterfas, M., S. Mouaziz, and R. S. Popovic. "14 GHz longitudinally detected electron spin resonance using microHall sensors." *Journal of Magnetic Resonance* 282 (2017): 47-53.