Diamond turned Lithium-Niobate: ultimate quality for frequency combs and up-conversion

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Light can only interact with light in the presence of a nonlinear environment. One of the commercially most successful nonlinear materials is single crystalline lithium niobate. Even with the best nonlinear material high optical fields are necessary for efficient nonlinear interactions. In the quest to achieve the highest efficiency for the nonlinear processes I will present our method of fabricating some of the highest quality lithium niobate resonators [1]. The resonators are based on the whispering gallery mode design and I will briefly highlight two applications of these resonators.

Common to both experiments is a high-quality diamond turned and polished, millimetre sized lithium niobate (LN) whispering gallery mode (WGM) resonator, coupled to a microwave cavity. In the WGM resonator both the microwave and the optical fields are enhanced close to the rim of the WGM resonator and strong mixing mediated by the high second order nonlinearity in LN allows for both Sum- and Difference Frequency Generation (SFG & DFG).

![Schematic of the setup for the creation of electro-optic \( \chi^{(2)} \) frequency combs. The interacting fields are resonantly enhanced by an optical lithium niobate (WGM) and an external 3D metallic microwave cavity.](image)

Careful tuning of the phase matching in the hybrid systems leads to two different outcomes:

**Electro-optic frequency comb generation** In a system with symmetrically spaced optical modes and high microwave powers, both SFG and DFG can cascade leading to a comb with more than 180 comb lines at modest microwave and optical powers [2]. We will discuss the width of the comb and its use in wavelength division multiplexing in the telecommunication domain.

**Microwave-to-optical frequency conversion** In the limit of low microwave powers only the first sidebands exist. Carefully selecting an avoided crossing of two intrinsically coupled optical modes results in an asymmetric spectrum of the optical modes, which can be tuned such that only SFG is allowed. This fundamentally noiseless process can transfer the quantum state of an individual microwave photon into the optical domain [3]. We will discuss the current state of our efforts in achieving this conversion in a cryogenic environment.