Fabrication limits of waveguides in $\chi^{(2)}$ nonlinear crystals and impact on quantum optics applications.

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Nonlinear optical processes are key to manipulate light and have been exploited extensively both in the classical and in the quantum regime for a wide variety of purposes. Common applications include multiple-channel frequency conversion, optical parametric amplifiers and oscillators, generation of squeezed states and frequency conversion for single-photon detection. High-efficiency and compact devices are critical for their applications in the lab and, more important, in every-day technology. Integrated waveguiding devices offer a stronger confinement of the light fields over longer lengths than bulk ones, thus increasing the interaction strength of the process and resulting in more efficient tools to control and manipulate light. Moreover, engineering of waveguides nonlinearities with tools already available for bulk devices will allow the generation of novel quantum states, like high-purity single photon sources. Finally, waveguides can be easily interfaced with fibre networks, making them ideal tools for the development of long-range quantum communication systems.

However, waveguide fabrication is imperfect, which ultimately limits the performance of any practical devices. It is therefore important to understand how these imperfections in the waveguide affect the desired process. For classical applications some efforts have already been made in the past to understand how fabrication parameters affect waveguide efficiency. Theoretical analysis have been performed for thin-film and slab waveguides and, experimentally, annealed proton exchanged lithium niobate (APE-LN) waveguides have been investigated.

In this work we present a detailed theoretical analysis of the impact of unavoidable tolerances in the waveguide production process on the performance of nonlinear integrated quantum devices, such as parametric downconversion sources or quantum frequency conversion. With the help of numerical simulations we examine different types of noise that could affect the waveguide structures and show how the phasematching efficiency, bandwidth and shape are degraded (see Figure 1). Through numerical modelling of the waveguide structure we are able to quantify the influence of imperfections for different types of non-linear processes and show that the technological limitations of the fabrication process can result in very different performances depending of the exact experimental parameters and the considered phase-matching conditions. Thus we derive ultimate limits for the implementation of tailored, non-linear high-performance integrated quantum optic devices.

We conclude that the fabrication requirements and tolerances are strictly connected to the desired process and its feature of interest (maximum efficiency, spectral purity, etc.). Therefore, to fully exploit the advantages of integrated optical waveguides, it is fundamental to study the link between the technological fabrication of the device and its nonlinear properties.

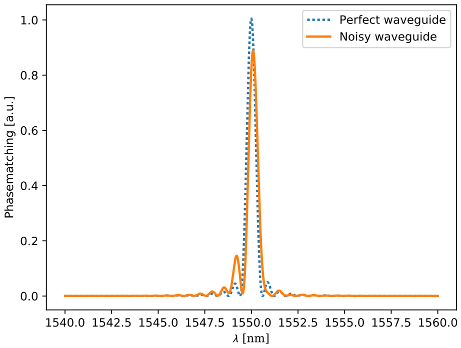

Figure 1: Simulation of the phasematching profile for a type 0 SHG (1550 nm→ 775 nm) for an ideal waveguide and a noisy waveguide.