Waveguide Fabrication and Optimization in Potassium Titanyl Phosphate

Abstract:
AdvR’s work involves the fabrication and characterization of optical waveguides in potassium titanyl phosphate (KTP) coupled to semiconductor lasers. For instance, these waveguides allow second harmonic generation (SHG) to frequency double the output of a narrow bandwidth semiconductor laser. Waveguides are also used to create external cavity diode lasers (ECDL) using embedded Bragg gratings in KTP, narrowing the spectral output of the semiconductor and increasing its coherence length. The accuracy of the final waveguide is influenced by each step of the photolithographic process. The focus during 2004-2005 has been to increase the accuracy of the waveguide structure using recent improvements to the Autostep 200 and refine the procedure at the new CNF clean room. Future efforts will include the exploration of non-metallic dielectrics as a mask for the pattern to allow in-process interrogation of the optical transmission of the waveguides.

Summary:
Periodic waveguides embedded in KTP wafers provide a novel approach to high efficiency QPM of laser light. A mask containing the periodic pattern is transferred onto the surface of the KTP wafer using 5x photolithography. Ion-exchange in molten Ba/Rb is performed on the patterned wafer, allowing ion-exchange to take place through the holes in the pattern. The ion-exchange process partially changes the composition of the KTP causing an increase in the index of refraction, which gives rise to total internal refraction containing the light within the waveguide. This periodic change in index sets up a Bragg grating for specific wavelength reflection. The ion-exchange process causes a domain reversal in the KTP lattice, giving rise to a periodic modulation of the nonlinear coefficient, which allows type-I QPM. The random and systematic errors introduced throughout the process from reticle manufacture to final lithography on to the KTP wafer critically impact the desired properties of the waveguide.

AdvR has successfully designed Bragg waveguides in KTP to stabilize the frequency of semiconductor lasers at 1319 nm with low phase noise, narrow spectral linewidth and high reflectivity. Several distinct periods, duty cycles, and widths of waveguides were designed to compensate for variations in modal confinement (and thus the modal index) of the waveguide that can arise from substrate differences and exchange depth.

The 5x projection photolithography step was improved during 2004-2005 due to an upgrade in the Autostep 200 stepper used to expose the pattern onto the KTP substrates. CNF staff were able to add an auto tilt feature to the wafer handling stage that can compensate for wedged or non flat variations in small KTP samples < 15 mm. Tilt was corrected by as much as 20x on some wafers! This greatly reduced variations along the length of the waveguide, improving the overall conversion efficiency at a specific SHG period and optical properties of the Bragg reflection.

Both the improvement in AdvR’s mask design and the addition of tilt for small samples in the Autostep 200 enabled AdvR to achieve much narrower Bragg reflections with higher reflectivity than we have ever achieved in the past. AdvR greatly appreciates the extra effort the CNF staff made in response to our specific needs.
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Figure 1:
Throughput of broadband light coupled into a waveguide with Braggs embedded into the KTP. Design and actual data show the successful overlap of narrow bandwidth (0.085 nm) reflections from the waveguide. This is an improvement in bandwidth by over 50% as compared to previous waveguide fabrication.

Figure 2:
Simple ECDL with KTP Bragg waveguide and a magnified image of the patterned KTP wafer.