Lithium Niobate Ring Resonator Device for Adiabatic Wavelength Conversion

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Primary CNF Tools Used: JEOL 9500, AJA ion mill, Oxford 100 PECVD, Plasma-Therm 72 and 740 etchers, AJA sputter deposition, CVC SC4500 evaporator, Zeiss SEM, Xactix xenon difluoride etcher, ABM contact aligner, Heidelberg mask writer - DWL2000, DISCO dicing saw

Abstract:

We are working on a brand-new method to change the frequency of light after its emission from laser by applying an electrical signal to ring resonators. Such a novel device will get rid of an optical pump or a gain medium in nonlinear frequency conversion.

Summary of Research:

Changing the frequency of light outside the laser cavity is typically done by nonlinear process like four wave mixing. However, integrating a system with high power optical pump into a photonic chip is a challenge. To achieve on-chip optical frequency conversion, we are working on a method of electrically tuning of ring resonator to go through adiabatic wavelength conversion. With this technique, we can dynamically control light in cavity within photon lifetime by tuning coupling between ring resonators electrically. Moreover, such a novel device will simplify and compact telecommunication components like wavelength-division multiplexing (WDM) with single frequency light input.

In previous work, adiabatic wavelength conversion (AWC) is achieved in silicon ring resonators [1-3] by using strong optical pumps incident on the cavity from above the chip. Similar to tuning frequency of sound by changing the length of the string, we can do the same to light wave by modulating the refractive index of the cavity. The light trapped inside the cavity shifts its frequency with resonance shift of the resonator. In silicon platform, the optical pump is absorbed and generates free carriers, which causes a change in the refractive index of the cavity. However, AWC in silicon introduces an optical loss, which reduces the photon lifetime and limits the conversion efficiency. It also requires a femtosecond timescale high power pulsed laser, which limits the scalability of AWC platform.

We are developing a method for electrical frequency conversion on a lithium niobate on insulator (LNOI) integrated photonic platform, the existence of which enables ultra-high quality resonators for long photon lifetime. Besides, lithium niobite has a large electro-optic effect and allows instantaneous changes in the refractive index, making it an ideal material for electrical AWC.

The LNOI sample we use consists of 600 nm thick lithium niobate (LN), 4.7 μm thick thermal SiO_2 bottom isolation layer and 0.5 mm thick silicon handle. We deposit electron -beam resist maN-2405 on the top of the sample with Surpass 4000 as adhesion. Ring resonators and waveguides are patterned with e-beam lithography process. Lithium niobate is usually etched physically with argon ions to avoid the non-volatile lithium fluoride byproducts shown in fluorine based etching techniques [4]. We etch 350 nm of LN in AJA ion mill and left a 250 nm LN slab. The resist is stripped with oxygen plasma in the PT72 etcher. However, we found that oxygen plasma can hardly remove the micro-masking formed by the interaction between argon and resist. Hence, we put the sample in RCA-1 silicon wafer cleaning process for 45 min to fully remove the residue on the sidewall. We check the sample with a scanning electron microscope (SEM) to make sure that micro-masking is completely removed before further moving on.

After the waveguide pattern is defined, we deposit a thin layer of SiO_2 with plasma-enhanced chemical vapor deposition (PECVD) to protect the waveguides. To pattern the bottom electrodes besides the waveguide, we deposit double layered PMMA and went through another e-beam process, which ensures a tolerance within tens of nanometers. We chose an evaporator as the metallization method to deposit Pt with Cr as an adhesion layer, which can further reduce the production of debris.

After an overnight lift-off, we deposit 2 μm SiO_2 with PECVD. Via holes are patterned with contact aligner and etched with a CHF_3/O_2 recipe of PT72 to expose the bottom electrodes. Top electrodes, designed to be bridges connecting two bottom electrodes and serve as contact pads to probes, are also patterned with contact aligner because the tolerance can be up to several microns. The AJA sputter tool is needed because the sidewalls of the via holes have to be covered or it will be an open circuit. And then a second lift-off process is proceeded.

We found that the top cladding oxide will break and fall off when the dicing saw goes through it, making the input coupling fairly poor. We also tried polishing, but realized that it's not easy for a holder to clamp a 1 mm wide chip. As a result, we tried to use etching method to get smooth facets. The facet is also patterned with contact aligner. Before the dicing, we used PT740 to etch the top and bottom SiO_2 cladding as well as LN slab with ion mill. After the dicing process, chips are put into the xenon difluoride etcher to undercut the silicon substrate.

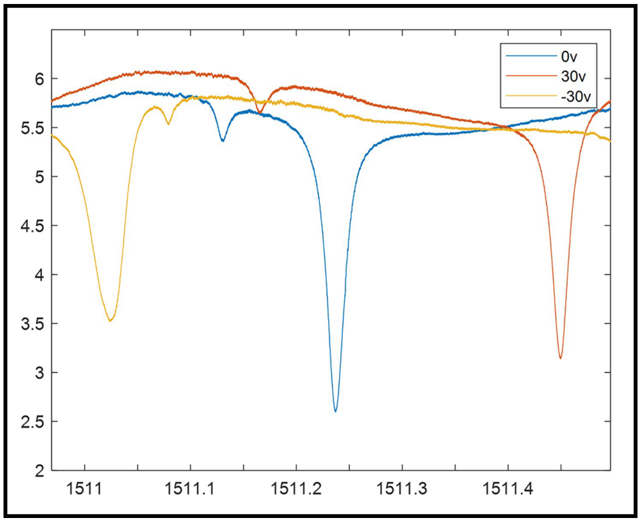

Figure 1: Spectrum of ring resonator when applying voltage.

We test the spectrum of the ring resonators we produced. It shows the loaded quality factor of around 100k, which corresponds to intrinsic quality factor of 170k. We also applied voltage to the device to test the electro-optics efficiency. As shown in Figure 1, the blue curve is the original spectrum without voltage applied. Red and yellow ones are the spectrum when we apply positive and negative 30V. It shows that the electro-optic efficiency is around 7pm/V. These results meet the criteria for an AWC device. We are now working on experiments to get the wavelength converted signal.

Conclusions and Future Steps:

We fabricated devices that show possibility for electrical AWC. We are now working on the experiments to get the wavelength converted signal. In the future, we will try to improve the quality factor and electro-optical efficiency of the devices.

References:

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