Electro-optic frequency shifting using coupled lithium-niobate microring resonators

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Abstract: We experimentally investigate electro-optic frequency shifting of continuous wave optical signal using harmonic RF signal. We demonstrate 11GHz shift with 98.2% efficiency and 1.25dB device insertion loss. This was accomplished by unidirectionally controlling the photon flow in frequency domain.

Frequency shifter, a device that translates the frequency of an input photon to another frequency, is an essential component of optical communication systems and quantum information technology[1-3]. Current technologies for frequency shifting are based on acousto-optics and optical wave mixing, and can result in optical frequency shifts in ~ MHz and ~THz range, respectively. Many applications, however, require frequency shifts in GHz range, which are hard to reach using the conventional approaches. Examples include translating the frequencies of single-photons to overcome inhomogeneous broadening of the quantum emitters, fine-tuning of the frequency of a laser beam (e.g. used for manipulation of quantum systems), and moving information from one telecommunication channel to another one.

Electro-optics has been widely utilized for controlling the spectrum of light in the GHz range. However, typical approach based on an electro-optic modulator driven by a single sinusoidal RF signal suffers from low shifting efficiency (< 50%). Solution to this problem is a serrodyne method[4] that uses a complex RF signal (e.g. a saw-tooth wave) to modulate the optical signal and provide uni-directional (up- or down-) frequency shift. However, the cost associated with generating non-harmonic waveforms at > 10 GHz frequency limit the applicability of serrodyne methods. Other methods for GHz frequency shift are also extensively studied[5-8], including phase modulator array and adiabatic tuning. Although some of the previous reports demonstrated frequency shift beyond 10GHz, it is still difficult to achieve high shift frequency, high efficiency, low insertion loss and low cost simultaneously.

Here we propose a new concept for a frequency shifter that relies on the control of the photon flow in frequency domain, and demonstrate this approach using coupled lithium niobate micro-ring resonators[9]. The device features 11GHz shift, 98.2% shifting efficiency, and 1.25dB on-chip insertion loss. Importantly, these figures of merit have been achieved using a single, sinusoidal continuous wave (CW) RF drive. Figure 1(a) shows the measurement setup for our frequency shifter. CW laser light is coupled into device and RF signal combined with DC bias are delivered through electric probe. The output light is measured with photodetector and optical spectrum analyzer. Figure 1(b) shows a scanning electron microscope(SEM) image of our designed frequency shifter.

We applied a 11GHz sinusoidal microwave to our device with CW light pump around 1630nm and measured the optical spectrum. The shift efficiency is defined as $\eta = P_{shift}/P_{out}$, where P_{shift} is the measured power at shift efficiency and P_{out} is the output power of light. At the same time, the device insertion loss is $IL = P_{out}/P_{in}$ with P_{in} is the optical power before going into device.

Figure 1(c) shows the measured output optical spectrum. The spectrum is normalized by the total output power P_{out} and the wavelength of pump laser is set to 0. It can be seen that at 11GHz the device features an efficiency of 98.2%. We also evaluated the device response for different RF frequencies, and found that for frequencies in the range of 9.3 – 10.4 GHz efficiency is > 90%. (at 8GHz the device efficiency is still high, ~ 80%). The device insertion loss (not including fiber couplling) is measured to be 1.25dB.

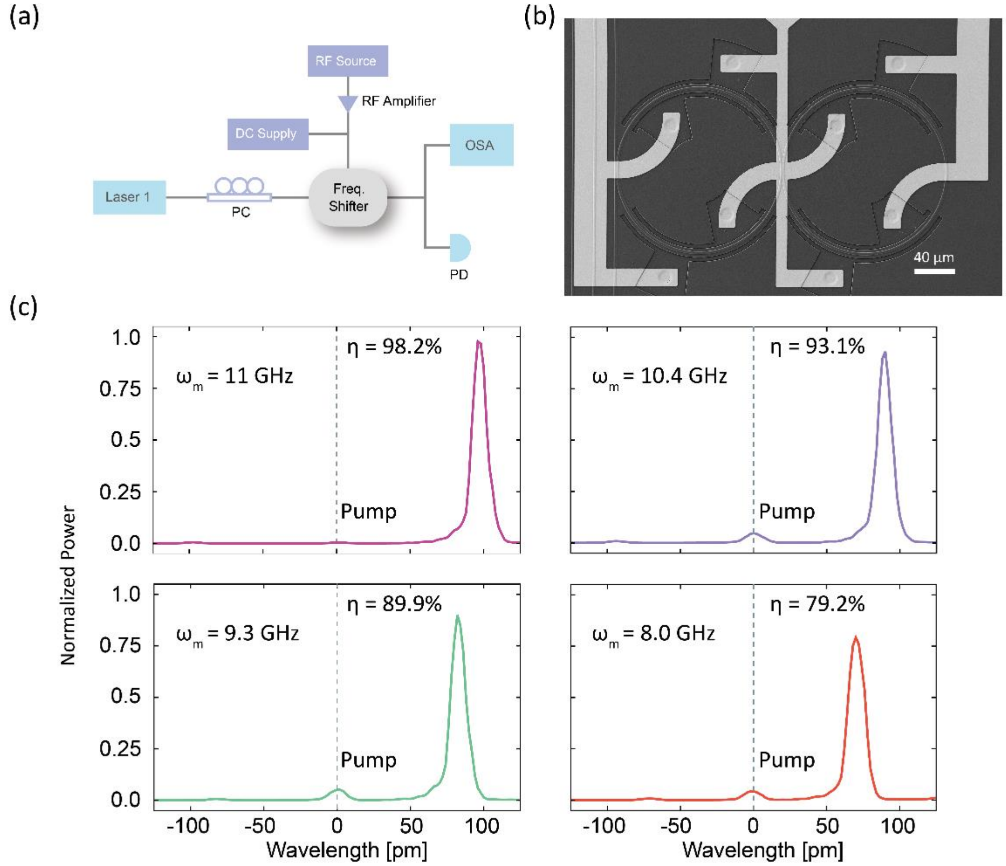

Figure 1 (a) measurement setup of our frequency shifter. PC, polarization controller; PD, photo detector; OSA, optical spectrum analyzer. (b) SEM of designed frequency shifter. (c) Measured output spectrum. Pump wavelength is set to 0. The output power is normalized by the total output power. The device insertion loss is measured to be 1.25dB.

In conclusion, we theoretically investigated the concept of controlling photon flow in frequency domain and implementing it in thin-film lithium niobate platform. Electro-optic frequency shift for continuous wave is demonstrated, featuring high shift frequency, high efficiency and low device insertion loss with the need of only one sinusoidal modulation.

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