A Polarization-independent Fast Light Switch

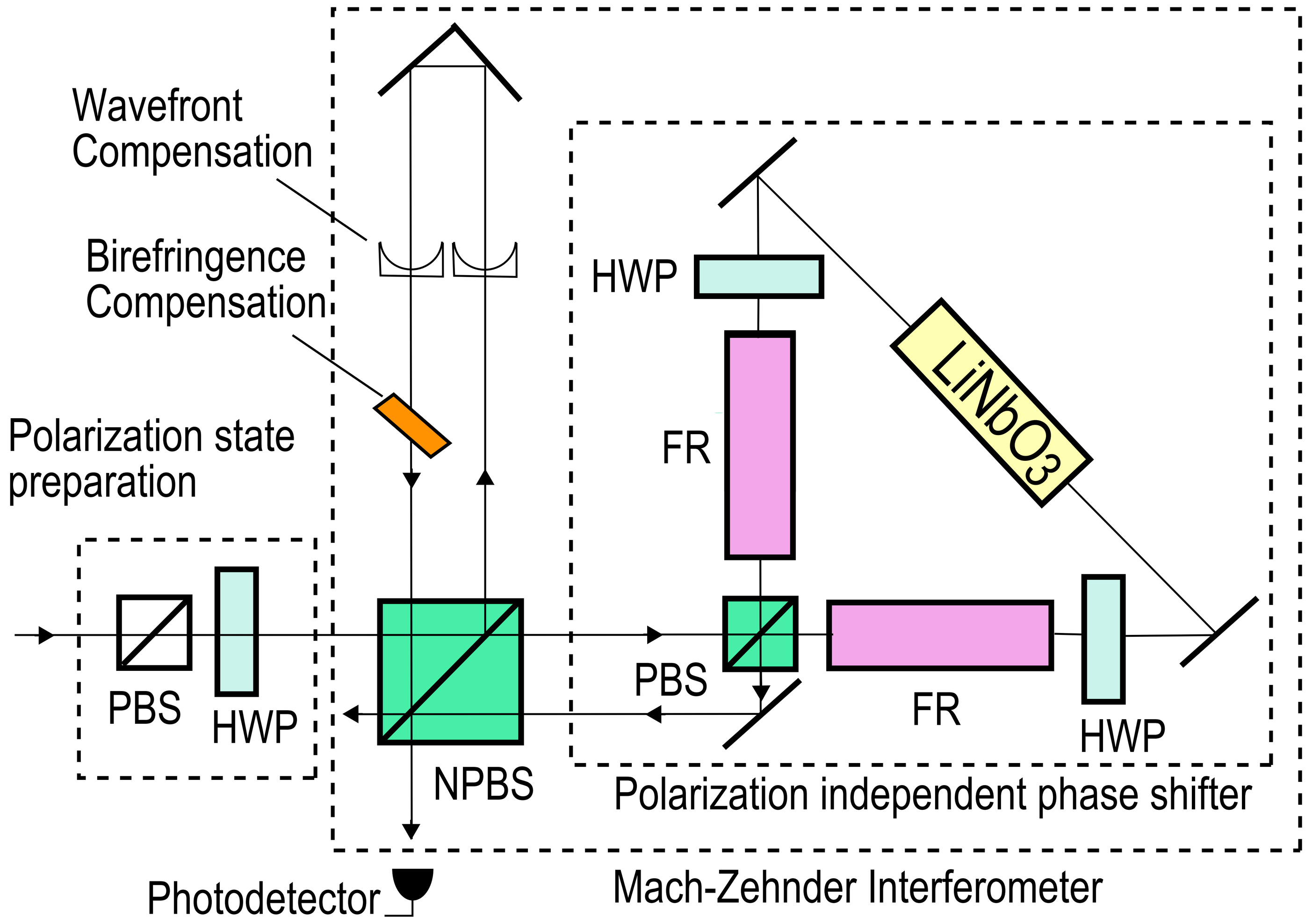
Ng Tien Tjuen, Darwin Gosal, Antia Lamas-Linares, Christian Kurtsiefer
Department of Physics, National University of Singapore

Motivation

Switching light on a time scale below 1 ns is a core building block of many photonic devices. However most optical communication applications are not required to do this in a polarization independent manner, and can tolerate large insertion losses. For implementing quantum logic operations using the polarization of photons as information carriers, a low loss switch leaving the polarization of the photon untouched opens a new range of applications: conditional measurement schemes, combined polarization state, time bin encoding and quantum computing with optical qubits[1]. The obvious choice of using a simple mechanical mirror for phase shifting is limited by the inertia of the optical element, making this approach impractical for switching times below one microsecond.

Basic Concept

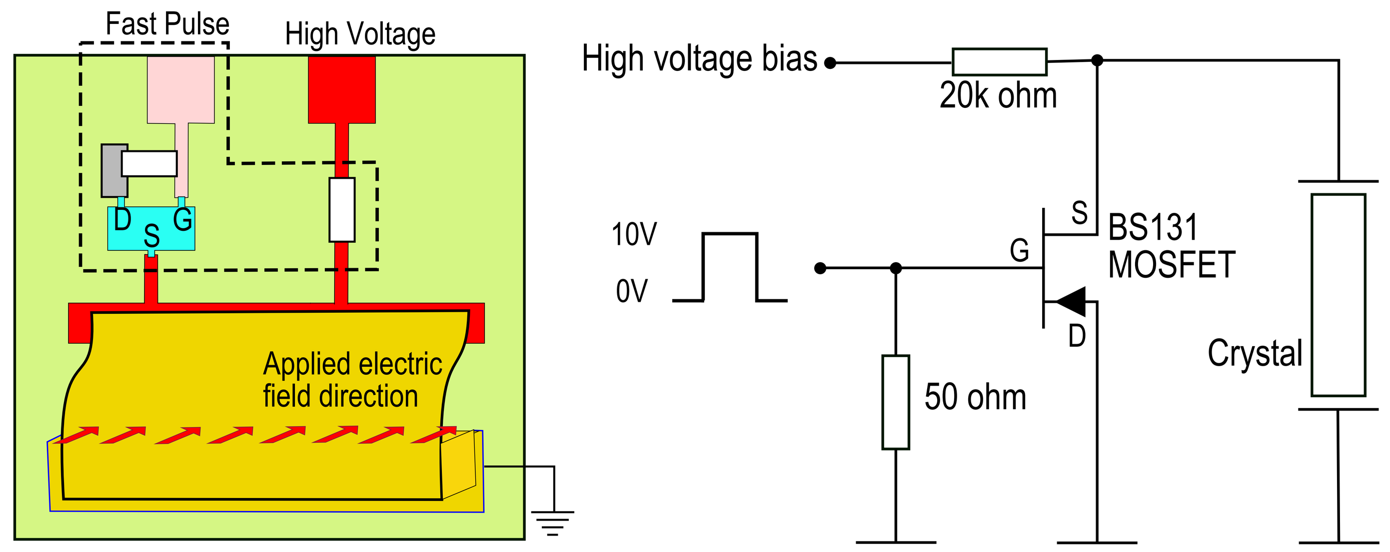
To address both low loss and fast switching time, we use an AR coated bulk 20mm long y-cut $LiNbO_3$ crystal with a cross section of 1×1mm as a phase shifting element, with the control field applied in transverse direction. To overcome long propagation times in compensated crossed modulators, we split the two polarization components of incoming light, and let them pass through the same modulator, but in counter-propagating directions. Two Faraday rotators, followed by half wave plates, ensure that the two orthogonal initial polarization components are transformed into the same polarization in the modulator (see figure below), and transformed back to their original polarization. Despite its relatively large geometrical size determined by the Faraday rotators, this topology does not restrict the modulation frequency or the optical bandwidth.



The polarization-independent phase shifter is combined with a Mach-Zehnder interferometer to form the final switch. In order to compensate the different effects on wavefront curvature and optical path length in this free space set-up, we extended the length of the reference path in this interferometer to arrive roughly at a zero optical pathlength difference for wide band light sources, and inserted a divergent lens pair to match the wavefronts.

Drive Circuitry

The half wave voltage of the modulator crystal is around 100V which needs to be switched in less than 2ns. The main component of the switching circuit is a MOSFET which discharge the voltage across the crystal from half wave voltage to zero. Gate pulses with a rise time of 400ps and a maximum voltage of 10V are provided via an impedence-matched line to the switch located closely to the modulator crystal to keep parasitic capacitance small. After the modulator crystal is discharged, it gets recharged to the half-wave voltage via a 20 kΩ resistor.

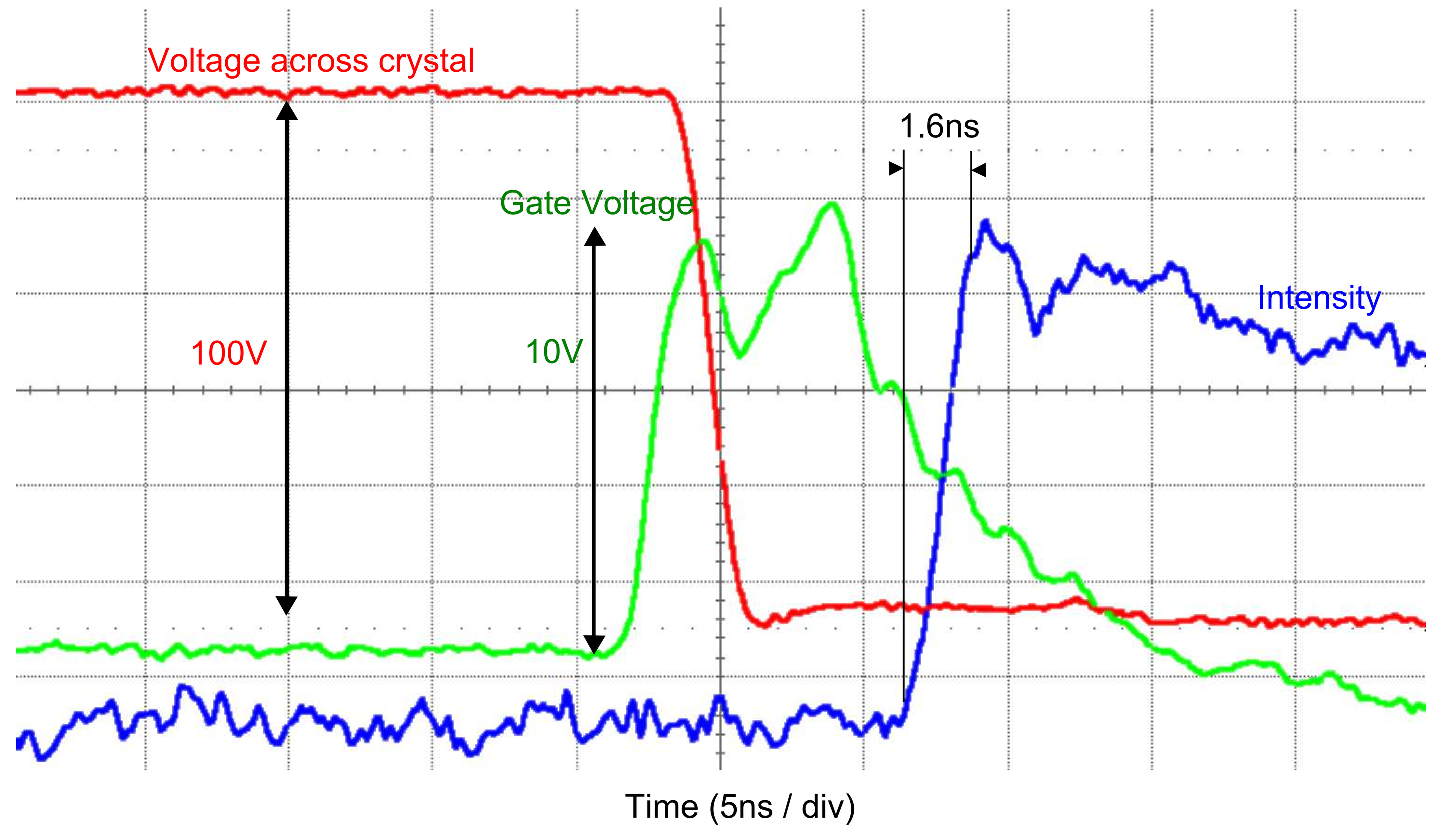


Switching Performance

The performance of the optical switch was verified both with a Helium-Neon laser at 633 nm, and a diode laser at 690 nm to emulate the wider band single photon source at 702 nm.

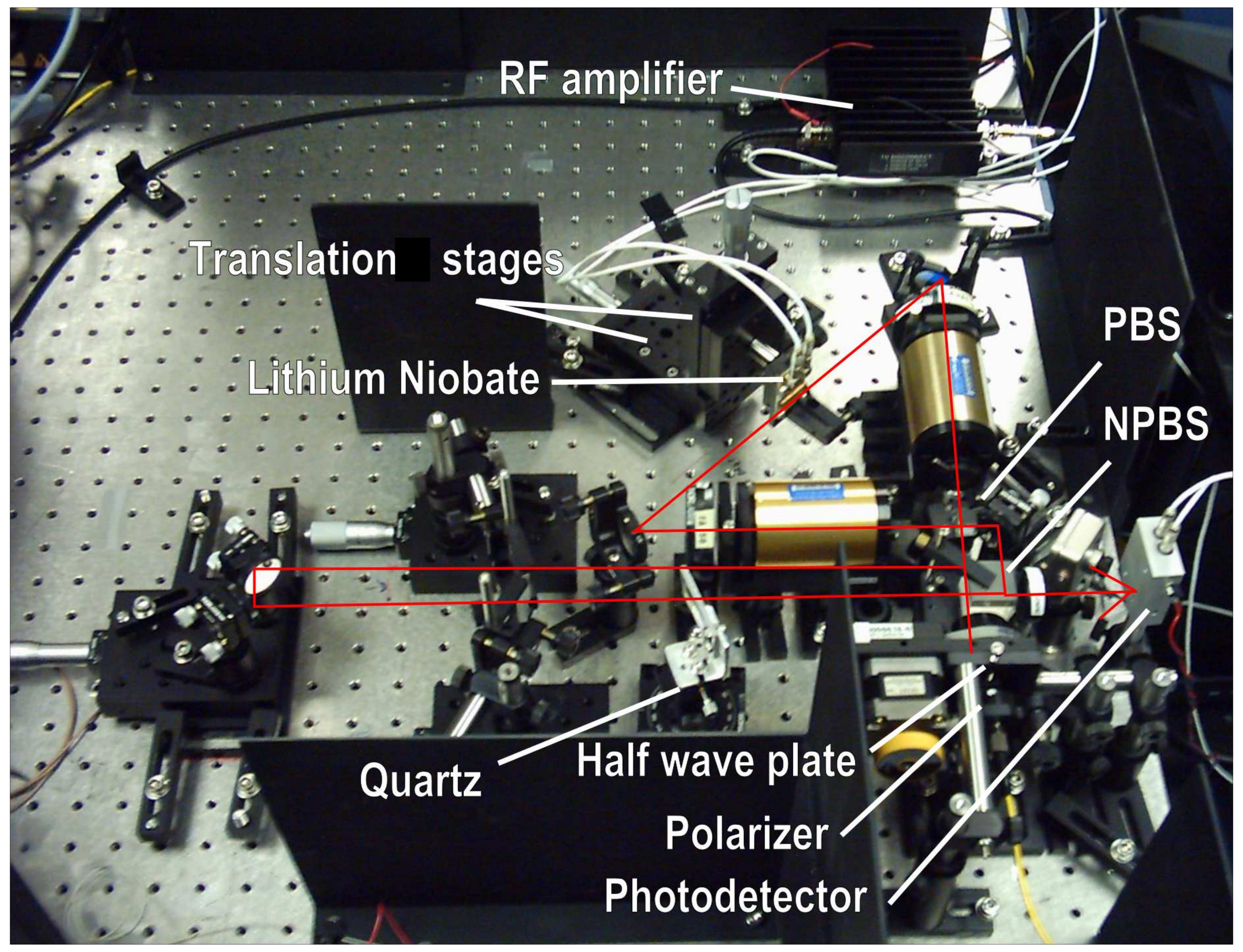
With the MOSFET (BSS131) co-located to the crystal, we achieve 1.6 ± 0.2 ns switching time (10% to 90% transition), detected with a high speed photodiode. A delay of few nanoseconds between the switching and the detection is due to the path length and the cable.

The repetition rate of our device is limited by the time constant $\tau = RC$ for recharging the crystal. We maintain the full change of a half wave voltage across the switch after a recharge and currently achieve a repetition rate of 100kHz.

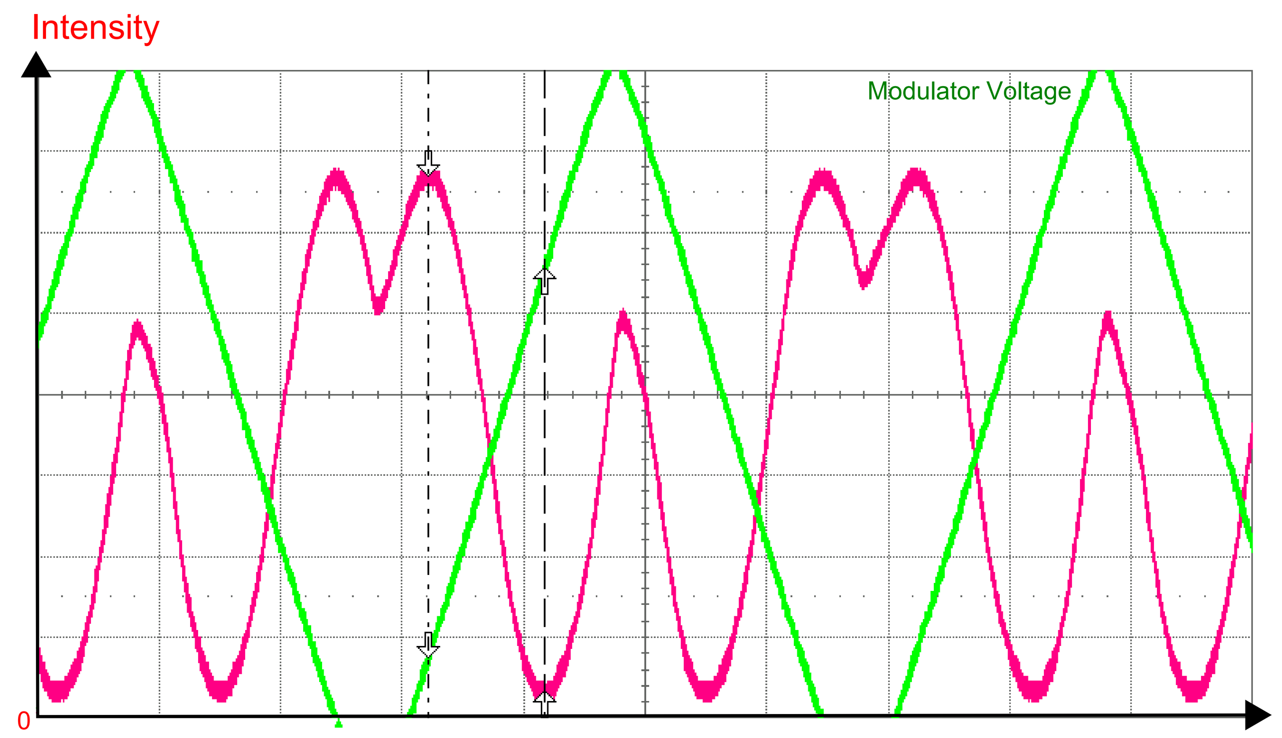


Experimental Setup

The visibility or on/off contrast of the switch for arbitrary polarizations was 96% for HeNe laser light, and 92% for the 690 nm laser diode. The limitation of the visibility seems to be wavefront mismatch in the Mach-Zehnder interferometer, and a non-zero optical path length difference. An imperfect polarization compensation of the beam splitting element and the retro-reflectors in the interferometer affects the visibility of both lasers.



Test of optical setup around the modulator crystal by driving the modulator crystal with a ramp voltage.



Next Steps

This setup will be a useful tool for photonic quantum communication experiments, e.g. for carrying out conditional measurements on entangled multi-photon states. The down converted light generated from a spontaneous parametric down conversion (SPDC) process will be the next source to test the performance of this device. In this application, one would like to direct one of the members of the pair between several alternative measurements without affecting its polarization state. Conditional measurements can help increase the efficiency of the quantum computing.

References

[1] Prevedel *et al.* *Nature* **445**, 65 (2007)