Photorefractive and pyroelectric photonic memory and long-term stability in thin-film lithium niobate microresonators

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Supplementary Information

1. Experimental setup

Figure S1 illustrates the schematic for the PR characterization setup, which consists of the control and probe laser beam paths for excitation and monitor, respectively. An erbium doped fiber amplifier is placed after the control laser to amplify and adjust the injecting optical power. Two wavelength division multiplexers are used to combine and separate the control and probe light at near 1546 nm and 1550 nm, respectively. By adjusting the polarization controller and the polarizer, we can pump light at the TE or transverse magnetic (TM) mode in the waveguide. The transmitted control light is monitored by a power meter, while the transmission spectrum of the probe light is recorded by a data acquisition card. The chip is placed on a TEC to keep at a stable temperature, preventing temperature-induced drifts during the photorefraction measurement. We evaluate both PR and PE effects by extracting the optical effective refractive index of the guided polarized mode (TE or TM) based on its cavity resonance shift under the light injection (for the PR experiments) or the temperature variation (for the PE experiments). Different polarization modes have different electro-optic coefficients. For example, γ_{13} = 9.6 pm/V is applied for TE mode in the Z-cut TFLN.

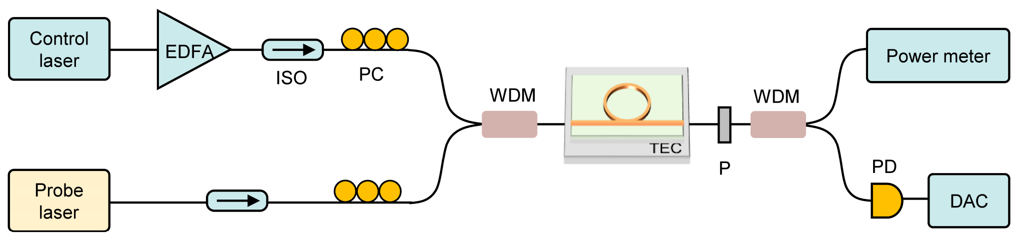

Figure S1. Experimental setup for characterization the PR effect. EDFA, erbium-doped fiber amplifier; ISO, isolator; PC, polarization controller; WDM, wavelength division multiplexer; TEC, thermo-electric controller; P, polarizer; PD, photodetector; DAC, data acquisition card.

2. Thermo-optic bistability and fast-relaxation PR in the Z- and X-cut LN microresonators

Figure S2 shows the forward (the short to the long wavelength) and backward (the long to the short wavelength) transmission spectrum of one optical resonance in Z- and X-cut LN microresonator. As the optical power increases from 3.2 dBm to 20.7 dBm in the waveguide, the resonance transmission spectrum is distorted regardless of the crystal orientations while the PR effect dominates in the Z-cut case and the TO effect dominates in the X-cut case.

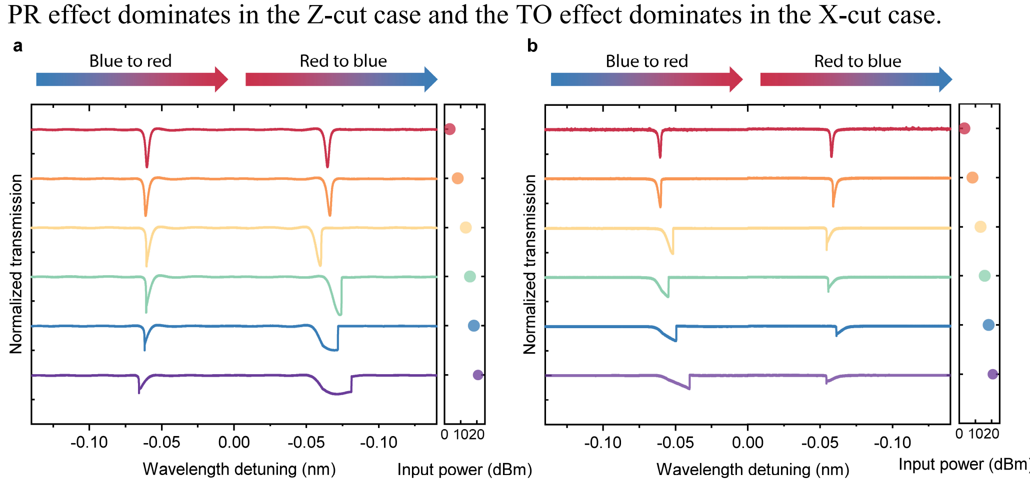

Figure S2. Forward and backward transmission spectra under different injection power in **a** Z-cut and **b** X-cut microresonators.

3. PE and TO response in different orientations devices

For X cut TE mode, we record the index change when heating up (red solid dots). It is followed by the subsequent temperature decrease (red cross dots), in which the index change still follows the original linear function. Thus, the PE effect in the X-cut LN also shows the rapid relaxation and the TO effect contributes to dn/dT of $3.2\times10^{-5}\ /\ ^{\circ}C$. Furthermore, we repeat this process in the X-cut for the TM mode with an extracted dn/dT of $2.2\times10^{-5}\ /\ ^{\circ}C$. The difference is due to the different TO coefficients for ordinary and extraordinary conditions, which agree with the literature [27].

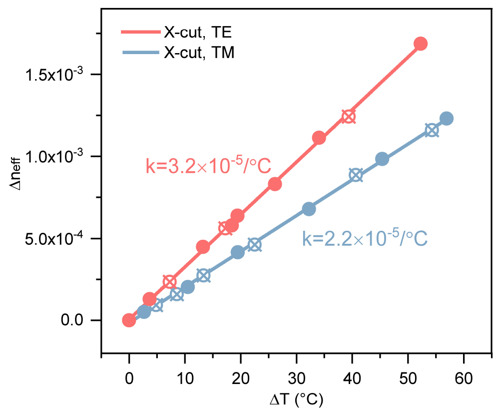

Figure S3. The measured wavelength shifts in the X-cut device with different polarization modes (red and green dots). The index change is due to the TO effect and shows no hysteresis when the temperature is ramped up and down. Solid dots: temperature ramp-up; Cross dots: temperature ramp-down.

4. Supplementary tables

Table 1. Fitted parameters of the PE relaxation

Fit item	a1	a2	T1 [h]	T2 [h]
70 °C	4.0×10^{-5}	7.7×10^{-5}	1.72	4.19
66 °C	1.6×10^{-5}	8.3×10^{-5}	0.56	3.06
63 °C	7.3×10^{-5}	6.9×10^{-7}	2.25	0.18
54 °C	2.1×10^{-5}	3.2×10^{-5}	1.16	3.71

Table 2. Summary of PR and PE effects in LN microresonators

Effect	Cut	Mode	dn/dT [/°C]	Recovery time
PR[a)]	Z-cut	TE	/	> 20 h
	X-cut	TE	/	fast

PE[b)]	Z-cut	TE	-2.9×10^{-6}	>10 h
TO[c)]	X-cut	TE	3.2×10^{-5}	fast

[a)] Photorefractive; [b)] Pyroelectric; [c)] Thermo-optic;