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Characterization of Heterogeneously Integrated Periodically-Polled Lithium Niobate using Optical Frequency-Domain Reflectometry

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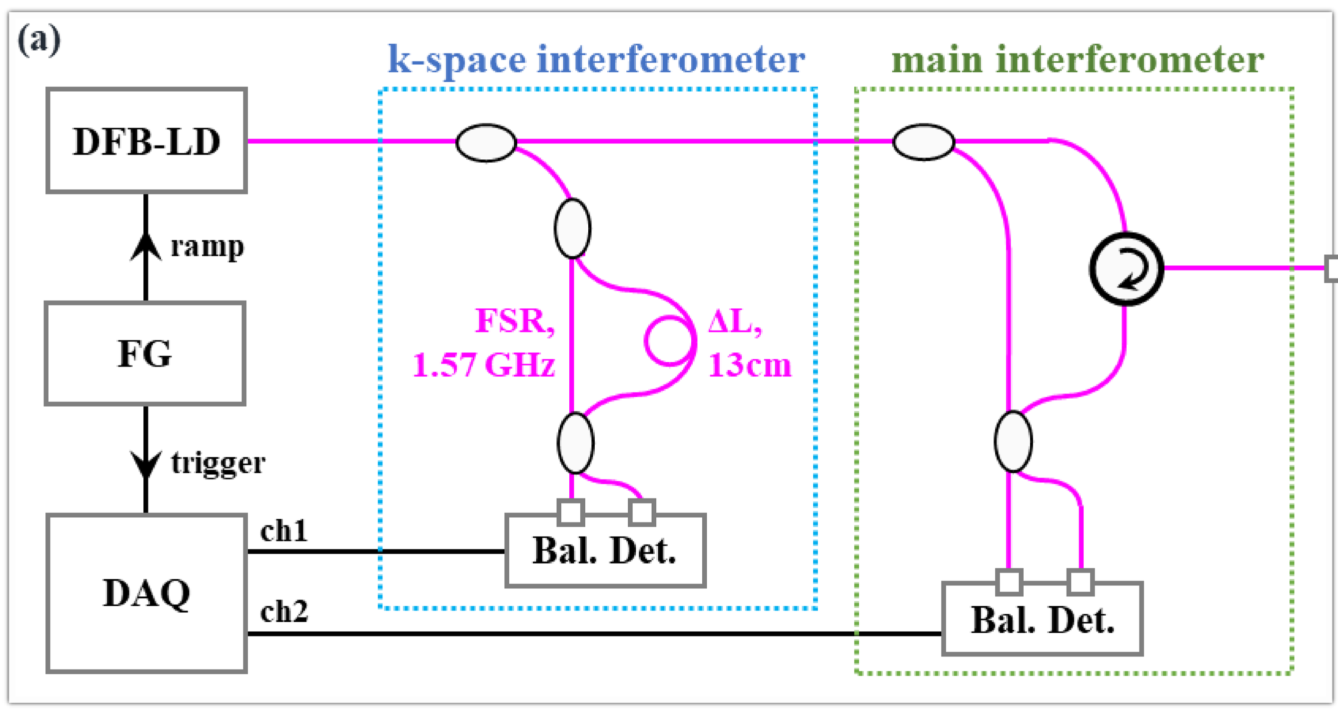
Abstract: Photonic integrated periodically poled lithium niobate (**PPLN**) is a promising device for **classical** and **quantum applications** due to its efficient nonlinear optical processing capabilities. This paper presents the characterization of heterogeneously integrated thin film PPLN that is assembled and packaged by PHIX, using optical frequency-domain reflectometry (**OFDR**), **operating at 1560 nm** with a **spatial resolution** of **1.5 mm** in air at **100 Hz measurement rate**. The sensing system enables detailed analysis of reflections potentially caused by refractive index mismatching at the coupling facets and by micro-structured periodic domain inversion within the PPLN.

OFDR reflectometer

Generation of FMCW by injection current modulation to DFB-LDs

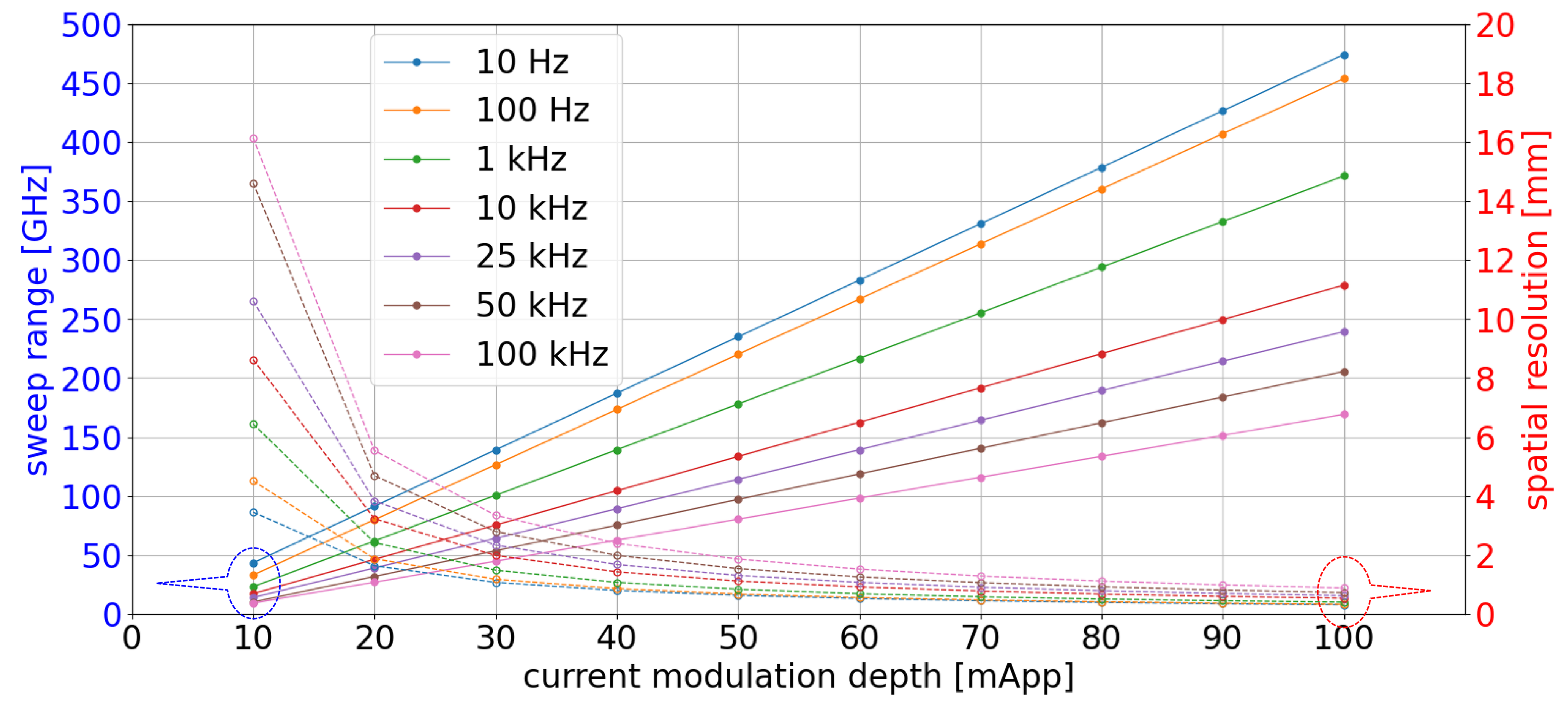
- Tradeoff between coherence length (ambiguity range) & frequency tuning rate (resolution)
- Laser cavity gain vs laser cavity volume
  - Longer gain chip, larger number of photon, longer photon lifetime, longer coherence length
  - shorter gain chip, smaller cavity volume, larger ΔT_{cavity}, larger optical frequency sweep range



Frequency sweep range vs sweep speed

FMCW characteristics of commercial DFB Laser

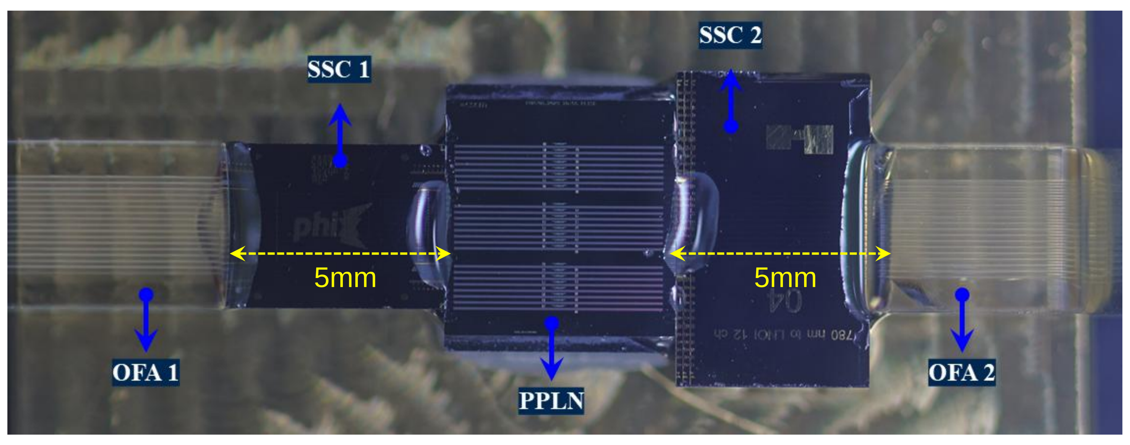
- Frequency tuning coefficient, strongly dependent on frequency sweep speed
  - Smaller frequency sweep range at higher speed due to slower thermal response of cavity
- Maximum measured frequency tuning rate, -4.77GHz/mA at 10Hz
  - FMCW sweep range of 474GHz at 10Hz; hence, spatial resolution of 316µm in air



Heterogeneously integrated PPNL

Spontaneous down-conversion from 780nm to 1560nm

- Squeezed state photons generation for quantum computing
- PPNL is 5 mm-long with poling period of 4.47µm.



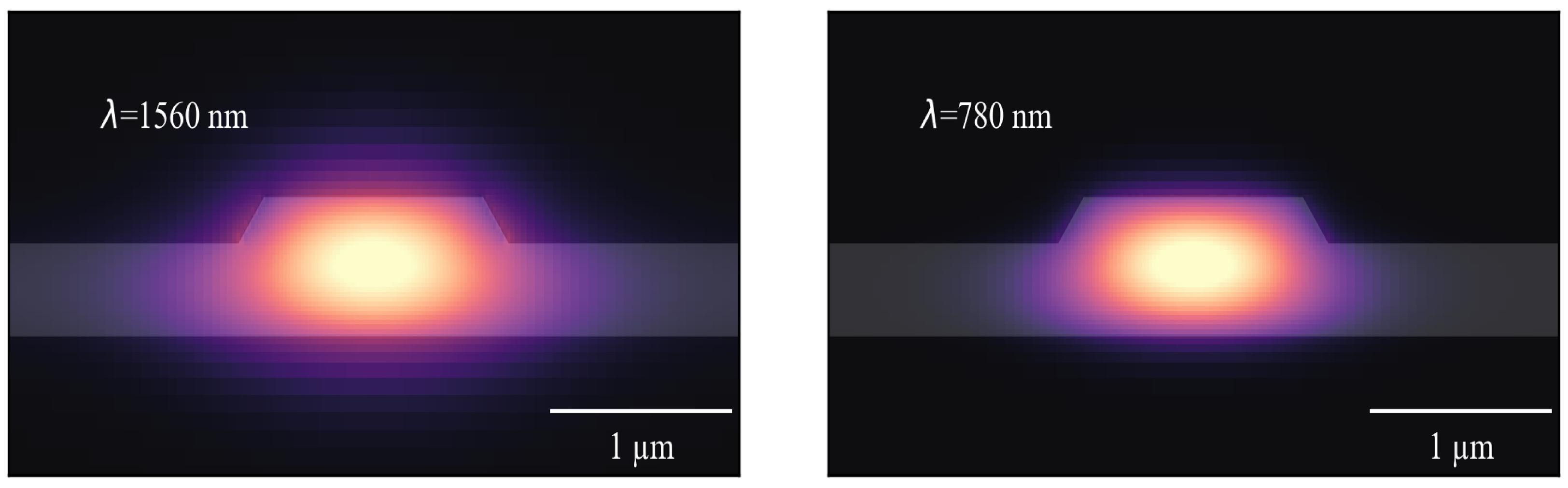
Insertion loss at 1550nm input, 6 dB
Insertion loss at 780nm input, 13 dB

OFA: optical fiber array
SSC: spot size converter
SSC1, optimized for 1560nm
SSC2, optimized for 780nm

Simulated mode profile on PPLN rib WG

Shallow etched WG to maximize mode overlap and conversion efficiency

- Measured conversion efficiency, 380%/W.cm^2

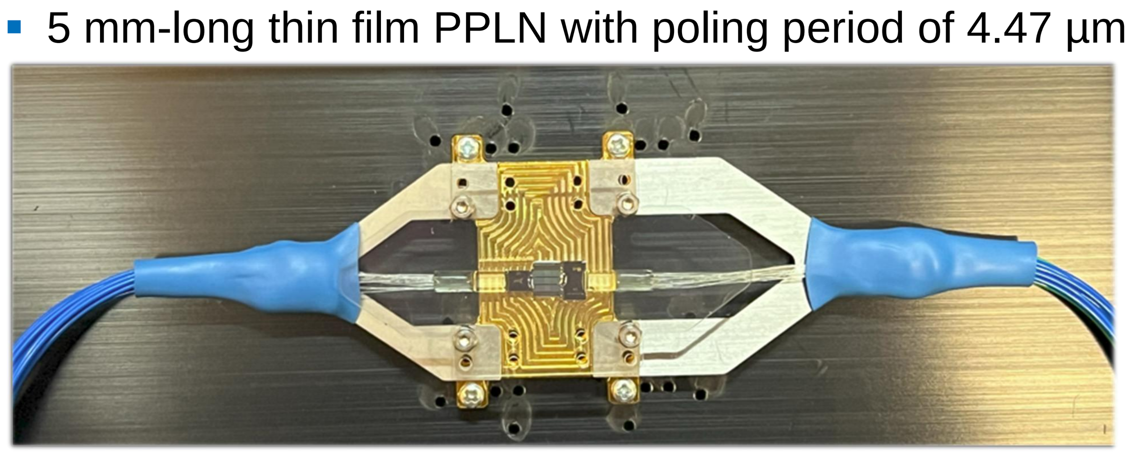


PPLN under test

Comparison between LOLIPOP PPLN & Commercial PPLN

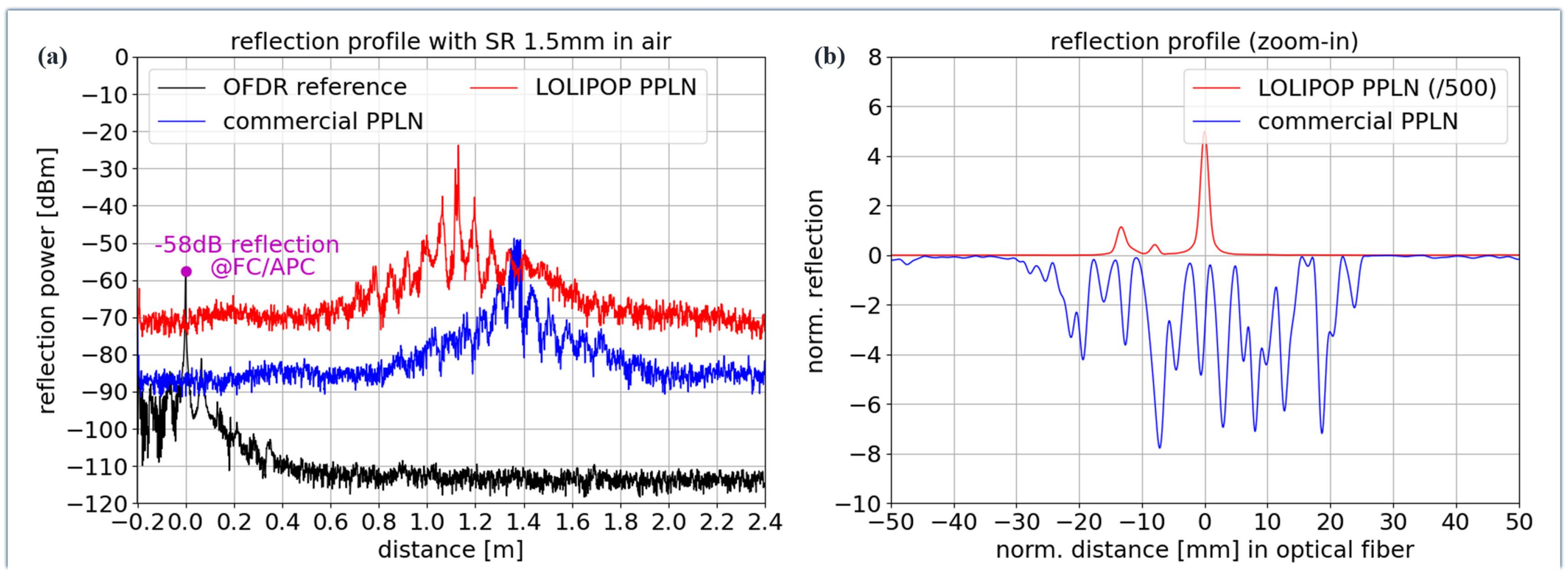
- Commercial PPLN as benchmark
  - 34 mm-long bulk PPLN with poling period of ~25 µm

- LOLIPOP PPLN is assembled and packaged by PHIX.
  - 5 mm-long thin film PPLN with poling period of 4.47 µm



Experimental results

- Noise floor of OFDR is measured to be -110dBm while the OFDR output power is 2.3 dBm.
- A presumably periodic reflection profile with a periodicity of 3.28 mm is observed over 45.3 mm.
  - Good agreement with actual length of 34 mm, when considering refractive index of bulk PPLN ~2.0.
  - No reflection from the coupling between optical fiber pigtail and bulk PPLN
- 3 strong reflections: -27.8 dB, -31.7 dB and -21.4 dB were observed at each facet.
  - Measured distances between peaks (5.4 mm and 7.9 mm) match well the actual length of SSC 1 and thin film PPLN, when considering effective reflective index n_{SSC}=1.52 and n_{PPLN}=1.92.



Conclusions

We have successfully fabricated and characterized periodically poled lithium niobate through the hybrid integration, combining two distinct platforms: silicon nitride and lithium niobate. The reflection properties along the fabricated PPLN are precisely investigated using an OFDR sensing system with a spatial resolution of 1.02 mm. Due to the complexity of the hybrid integration process, strong reflection in the range of -20 dB is present at each hybrid coupling facet. Such reflections can be problematic for applications that require the precise detection of signals counter-propagating through the device. Nevertheless, we believe that the in-situ monitoring of the device fabrication process by the OFDR sensing system offers a promising solution, for characterizing hybrid photonic integrated devices.

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