BGU Progress Report

# Tasks

* Theory development of efficient quantum pair sources on a chip in ppKTP
* Building the numerical simulator in ppKTP for 775-1550nm and 0.5Mcps/mW

# Studied waveguide architecture

## Initial simulated architecture

Initially we simulated double track waveguide schematically shown in Figure 1.

crystal axis

KTP crystal

*h*

gap

Figure 1 Initially simulated double track waveguide layout

w

Due to lack of experimental data, we initially assumed isotropic negative modification of the refractive index (RI) in tracks

with bulk index defined by Sellmeier equation [1]

We have simulated the modes of the structure shown in Figure 1 and found this structure supports **no guided modes** which means that one needs to additionally take into account RI modifications outside the track.

In the real double track waveguides wave guiding stems from the interplay of mechanical stresses induced during track formation. Due to the stresses the actual RI distribution appears more complex and involves zones with anisotropic positive and negative refractive index modifications.

To accurately model such modifications one needs either to retrieve the actual RI distribution from measurements or to involve modelling of defects formation by femtosecond laser pulses  [2–4]. However, reliable physical model of this effect, particularly, for KTP is yet lacking. The alternative is to perform heuristic modelling and/or fitting of the experimental data [4].

## Architecture with assumed stress-induced refractive index modification outside the tracks

To achieve wave guiding in the simulated waveguides we imposed certain assumptions. Namely, we assumed that increased index zones (which we call halos) appear around the tracks with the positive RI modification similarly to the result reported in  [5] for double track waveguides in fluoride glass. The halos were assumed to have a circular shape and Gaussian profile of RI. As for the tracks, the RI modification was taken to be isotropic

with

where is the distance from the halo center, and the amplitude was chosen to in accordance with the data reported in the literature [5,6]. The obtained structure is schematically shown in Figure 2.

*w*

crystal axis

KTP crystal

*h*

gap

Figure 2 Double track waveguide layout with stress-induced increased index zones (“halos”) around tracks

# Estimation of the down-conversion efficiency

## Theory

Following  [7] we define the down-converted signal power in the waveguide in a frequency interval as

with and interaction effective area

are the normalized mode field profiles of the pump, signal, and idler modes. The modal profiles are normalized so that which implies that have dimensionality of the inverse of a length.

Photon-pair source efficiency in photon counts/s per mW is obtained by

,

where pump power is taken as 1 mW.

Our assumptions on parameters are provided in Table 1

Table 1 Relevant parameters and assumptions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | **Description** | **Formula** | **Value** | **Units** |
|  | Collection efficiency of the signal photons to the detection system |  | 0.2 |  |
|  | Pump power |  | 1 | mW |
|  | Wavelength of signal and idler photons |  | 810 | nm |
|  | Central wavelength of the pump filter |  | 405 | nm |
|  | Passband of the pump filter |  | 1 | nm |
|  | Relevant nonlinear coefficient |  | 7.6 | pW/V |
|  | Effective nonlinear coefficient |  | 4.8 | pW/V |
|  | Length of the waveguide |  | 10 | mm |

## Calculation of the eigenmodes

For estimation of interaction effective area as well as poling period we have identified eigenmodes with a finite-difference mode solver.

We have identified that the waveguide supports guided modes provided that .

To find the waveguide parameters with the best down-conversion efficiency we have performed a multiparameter sweep calculating for each waveguide. The table below shows the swept parameters with the corresponding sweep ranges:

|  |  |
| --- | --- |
| **Parameter** | **Range** |
|  | 1-3 um |
|  | 10-24 um |
|  | 6-24 um |
|  |  |

Example mode profiles of the calculated signal, idler, and pump modes are shown in Figure 3. Dashed lines in plots designate intensity contours

.

A diagram of a number of objects

Description automatically generated with medium confidence

Figure 3 Signal, idler, and pump modes of a double-track waveguide

Using the obtained modal profiles, we have calculated interaction effective area for each configuration and identified the minimum among configurations with different .

Figure 4 shows of the best waveguide configurations for different values of RI modification and the poling period obtained for those configurations. The corresponding optimal waveguide parameters (track width, height and gap between the tracks) are shown in Figure 5.

Figure 6 shows the maximum spectral density at the central pump wavelength and the corresponding photon pair production rate assuming identical experimental setting as in  [7]. For instance, a value of pW/nm similar to the value reported in  [7] is obtained for . With the identical assumptions about the losses in experimental setup as in [7] this value corresponds to counts/s per mW of transmitted pump and approximately counts/s. Respectively, the value of counts/s can be achieved by increasing to the maximum value of used in simulations. We expect that further increase of will lead to the planned efficiency of 0.5Mcounts/s per mW although our assumptions on the RI distribution in case of stronger RI modifications requires validation.

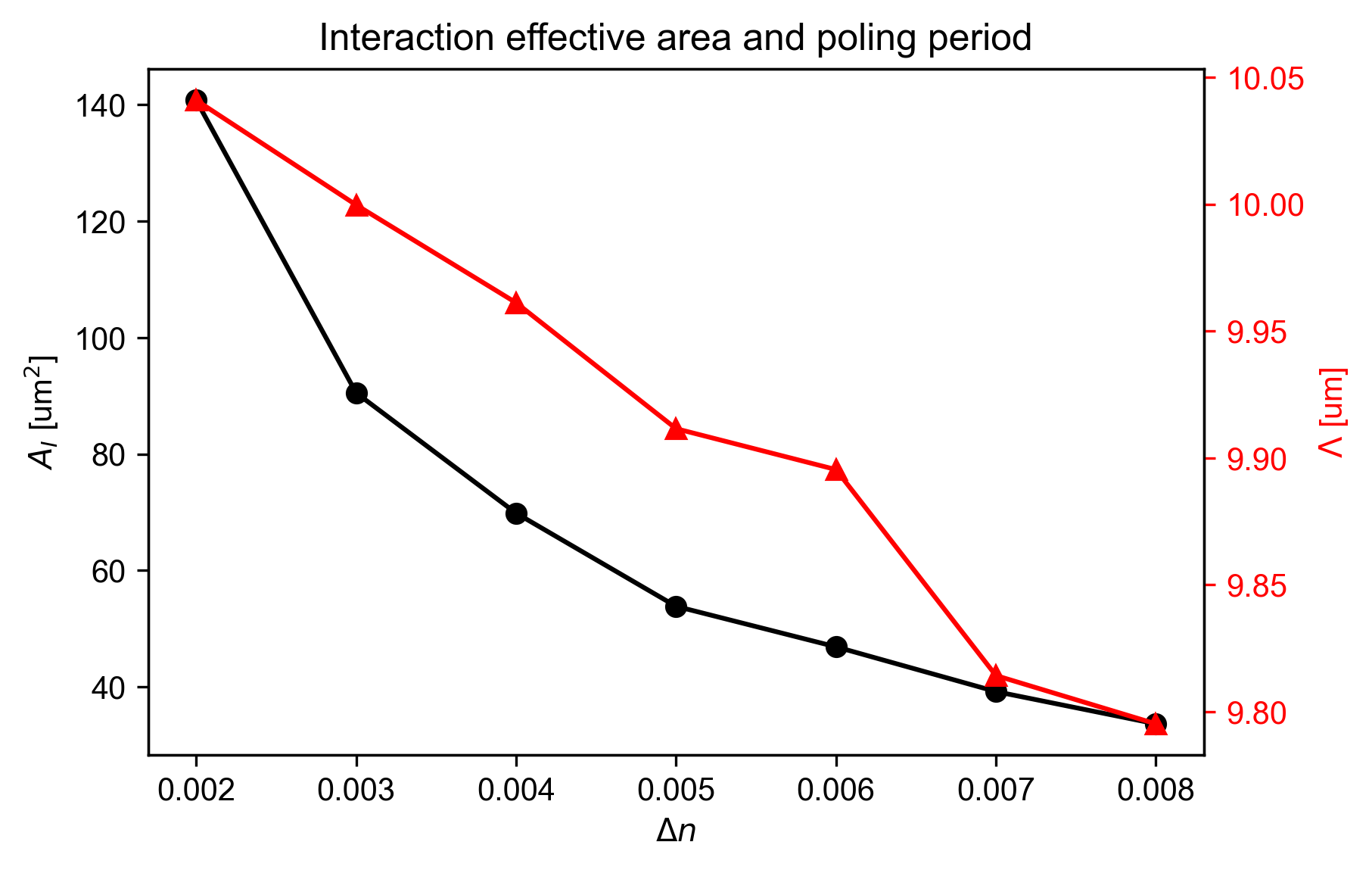


Figure 4 Minimum interaction effective area as function of .

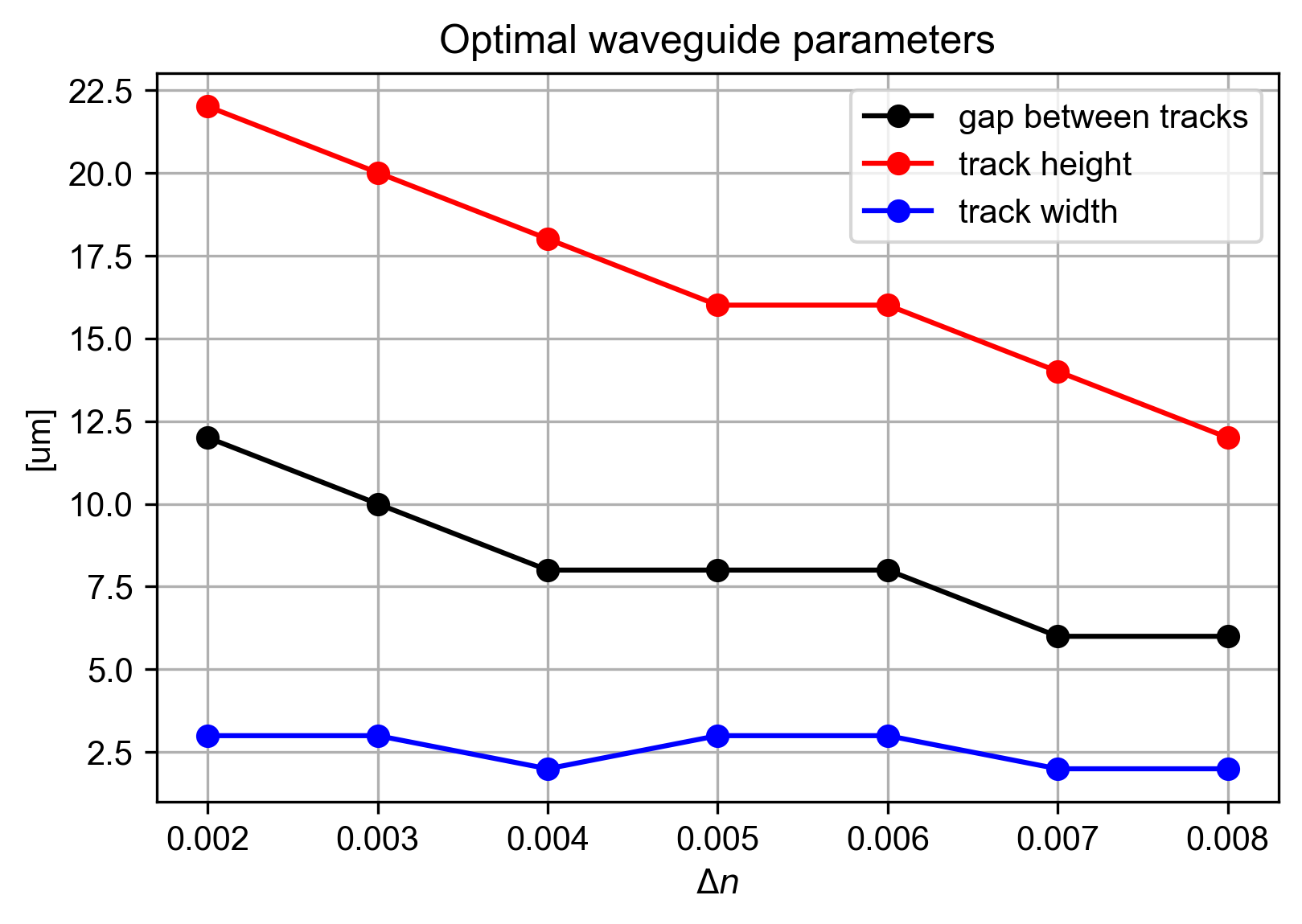


Figure 5 Optimal waveguide parameters as function of .

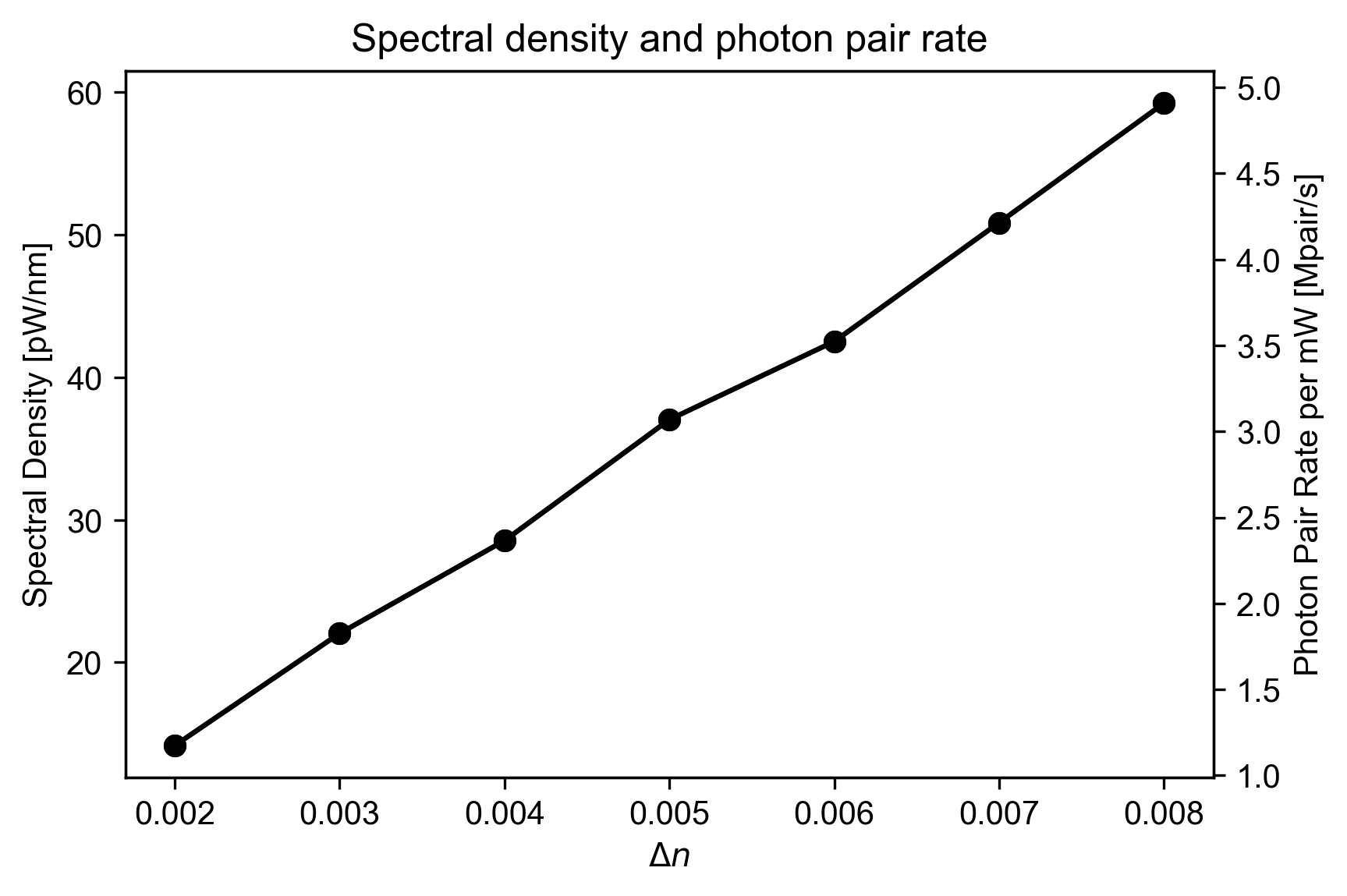


Figure 6 Calculated spectral power density of the signal photons for degenerate type-II SPDC per 1 mW pump power at nm, nm and the corresponding photon pair rate.

# Summary

To summarize, we have achieved the two milestones:

* Theory development of efficient quantum pair sources on a chip in ppKTP – ***accomplished***
* Building the numerical simulator in ppKTP for 775-1550nm and 0.5cps/mW– ***accomplished***

# References

[1] K. Kato and E. Takaoka, *Sellmeier and Thermo-Optic Dispersion Formulas for KTP*, Appl. Opt., AO **41**, 5040 (2002).

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[7] M. Fiorentino, S. M. Spillane, R. G. Beausoleil, T. D. Roberts, P. Battle, and M. W. Munro, *Spontaneous Parametric Down-Conversion in Periodically Poled KTP Waveguides and Bulk Crystals*, Opt. Express **15**, 7479 (2007).