Second order nonlinearities in silicon waveguide by interdigitated poling

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Nemo

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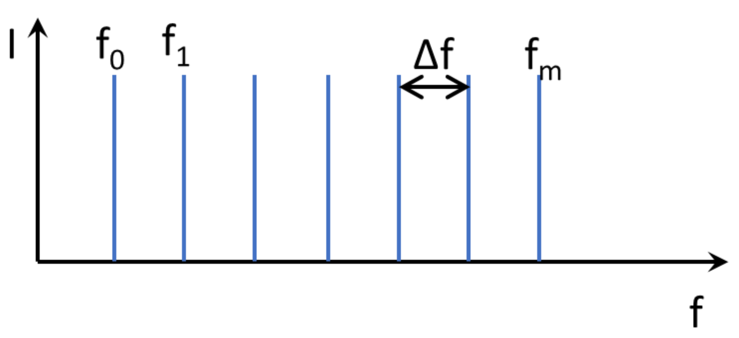
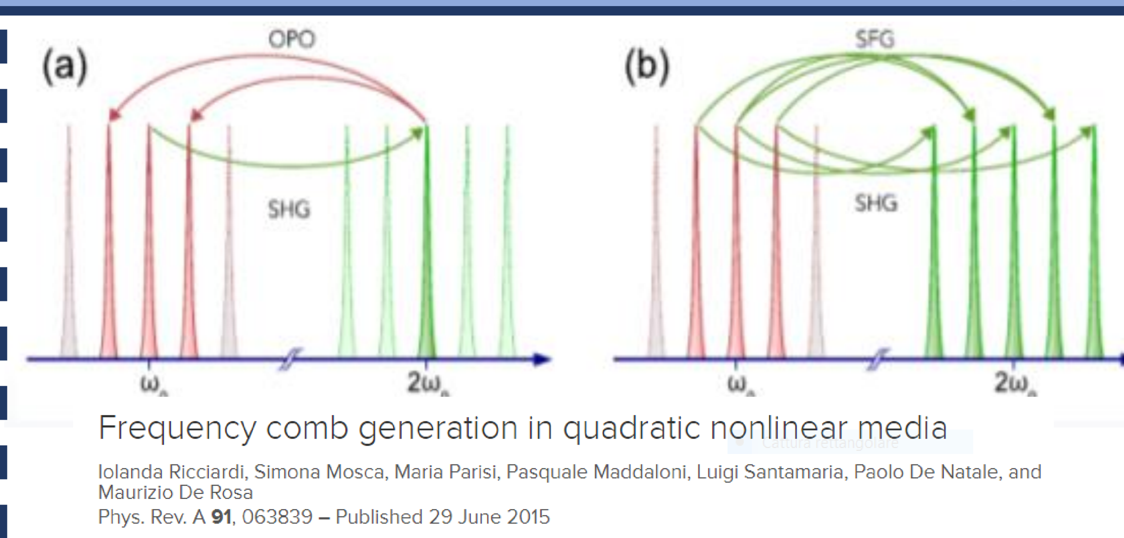
Optical frequency combs (OFCs) are light sources whose spectrum contains thousands of equally spaced laser lines. They have revolutionized precise optical frequency measurements by allowing a direct link from any optical frequencies to a reference microwave clock. In the NEMO national project, we propose a new class of chip-based OFC taking advantages of the higher efficiency offered by second order nonlinear processes.

The problem

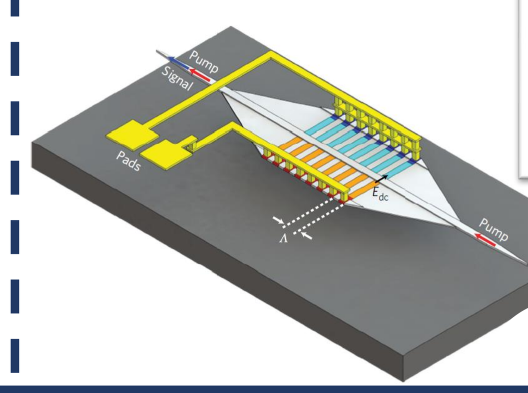
Optical frequency comb (OFC)





May arise entirely through second-order nonlinear optical effects: this requires low pump power and intrinsically leads to an octave span. ***What about using silicon?***

Silicon is centrosymmetric! ⟶ $\chi^{(2)}E^2 = -\chi^{(2)}E^2$

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Electric field-induced second-order nonlinear optical effects in silicon waveguides

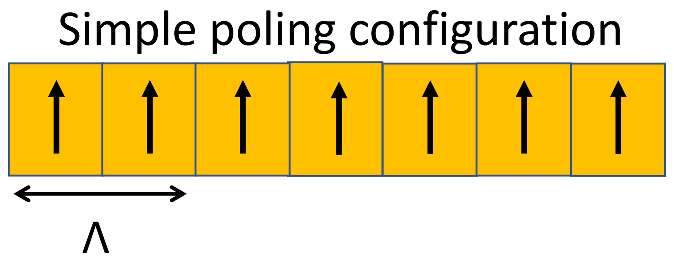
E. Timurdogan, C. V. Poulton, M. J. Byrd and M. R. Watts

$$\chi^{(2)} = 3\chi^{(3)}E_{DC}$$

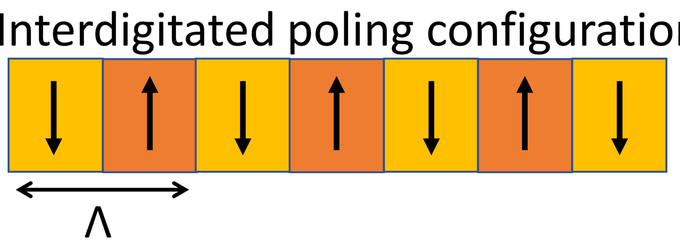
The sample

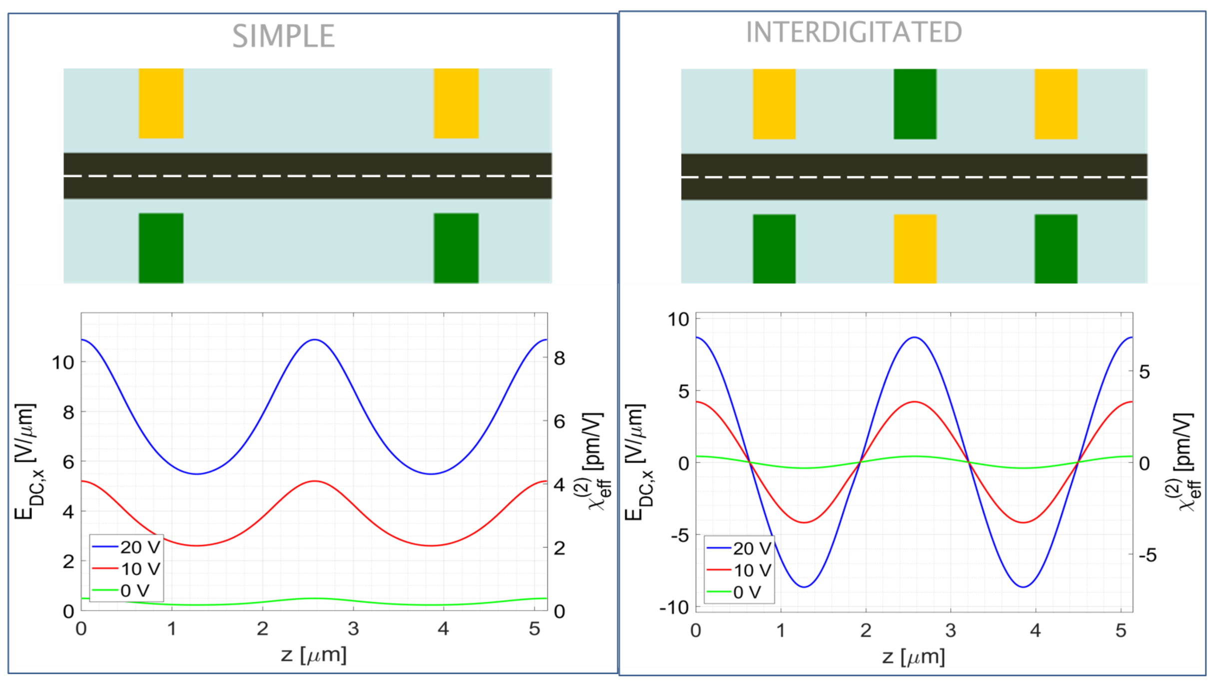
Periodic poling: $2k_{pump} = k_{SHG} - \frac{2\pi}{\Lambda}$

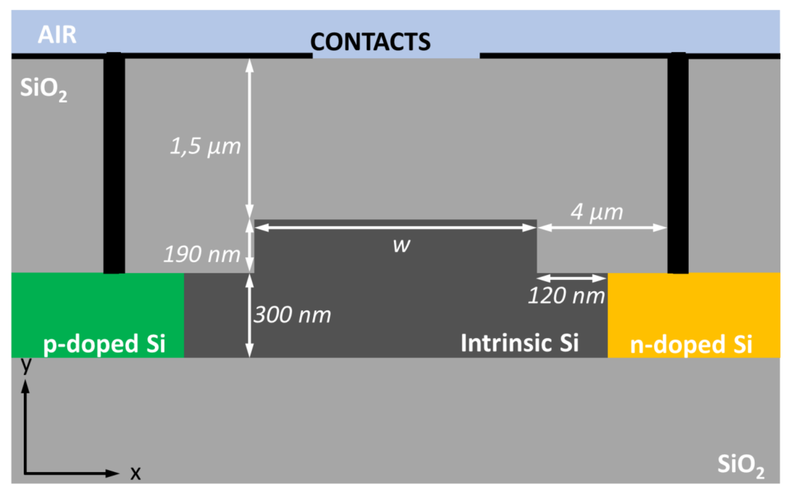
Simple poling configuration



Interdigitated poling configuration

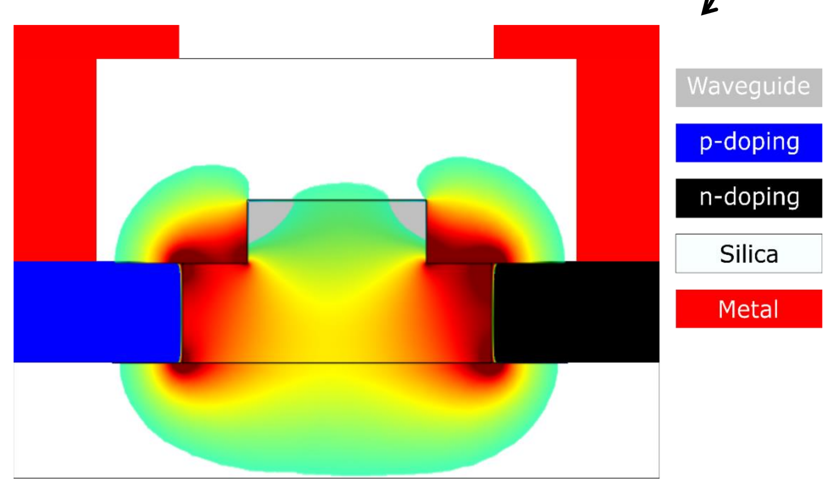






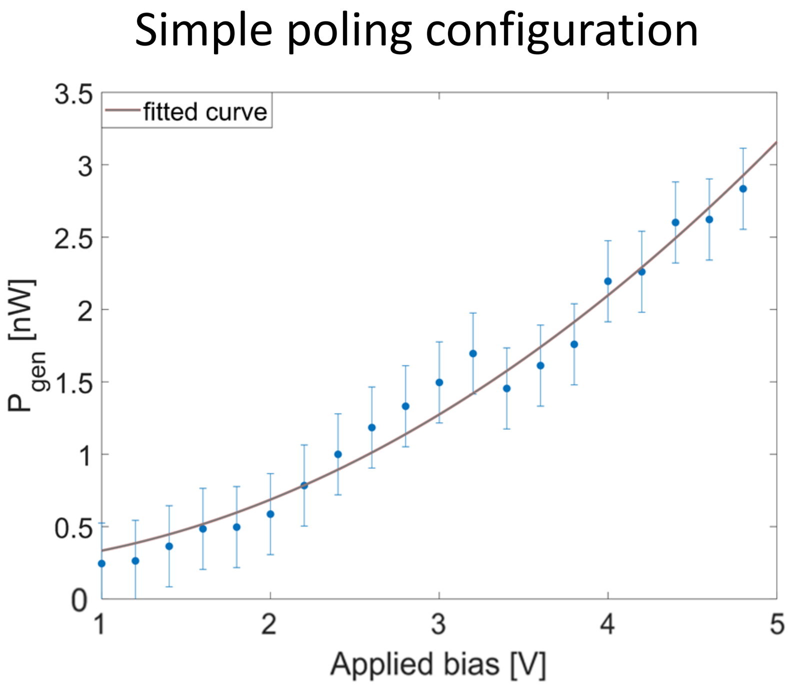
Geometry of the waveguide

Field applying a reverse bias

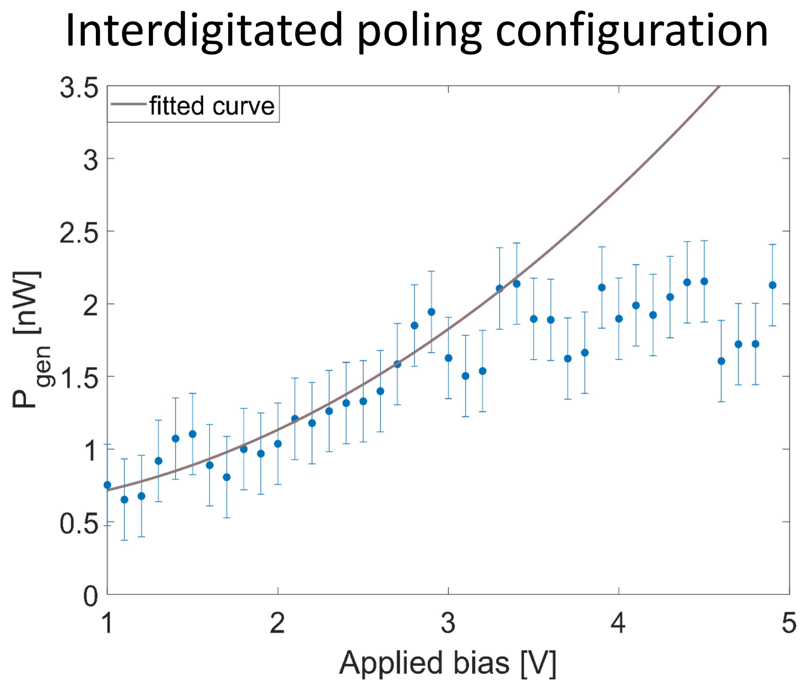


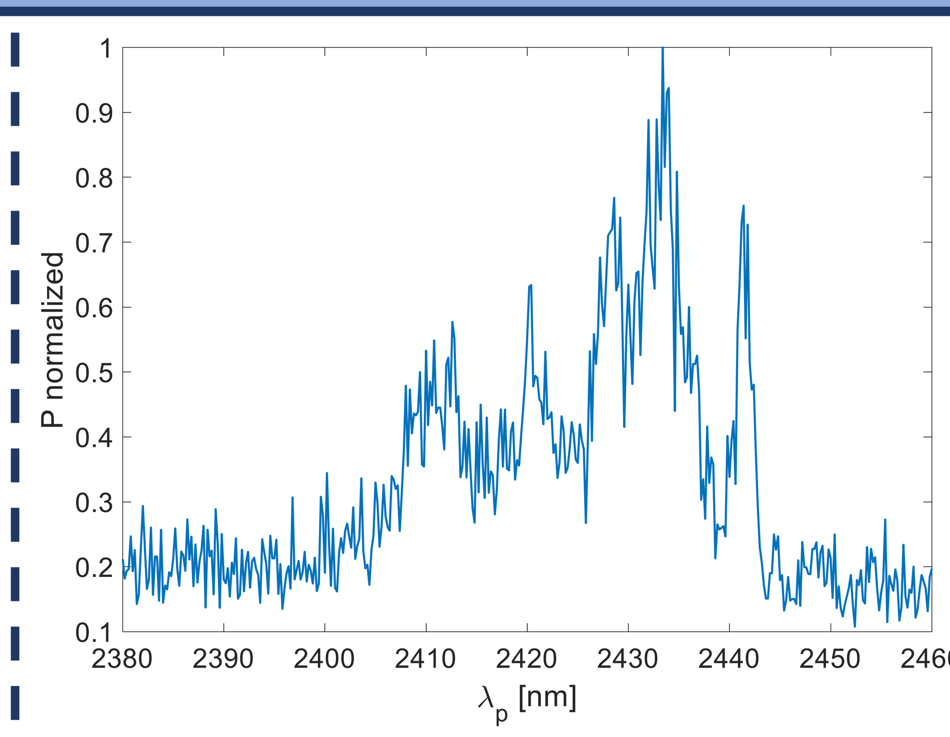
Experimental results

Simple poling configuration



Interdigitated poling configuration





$$P_{SH} = P_p^2 \left|\tilde{\gamma}_{SH}^2\right|^2 L^2 S$$

$$S = \frac{1}{L^2}\left|\int_1^L s(z)\, e^{i\Delta\beta z}\right|^2$$

Poling function:

Simple:

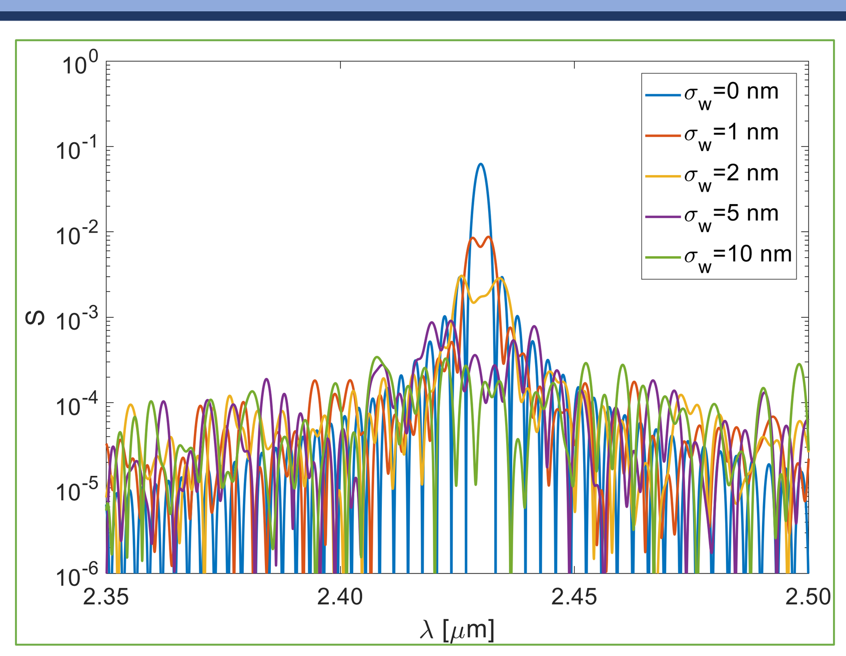
$$s(z) = \frac{1}{2}\sin\left(\frac{2\pi}{\Lambda}z\right) + 0{,}5$$

Interdigitated:

$$s(z) = \sin\left(\frac{2\pi}{\Lambda}z\right)$$

$$\Delta\beta = 2\beta_p - \beta_{SH} = 2\pi\left(\frac{n_{eff,p}}{\lambda} - \frac{n_{eff,SH}}{\lambda/2}\right)$$

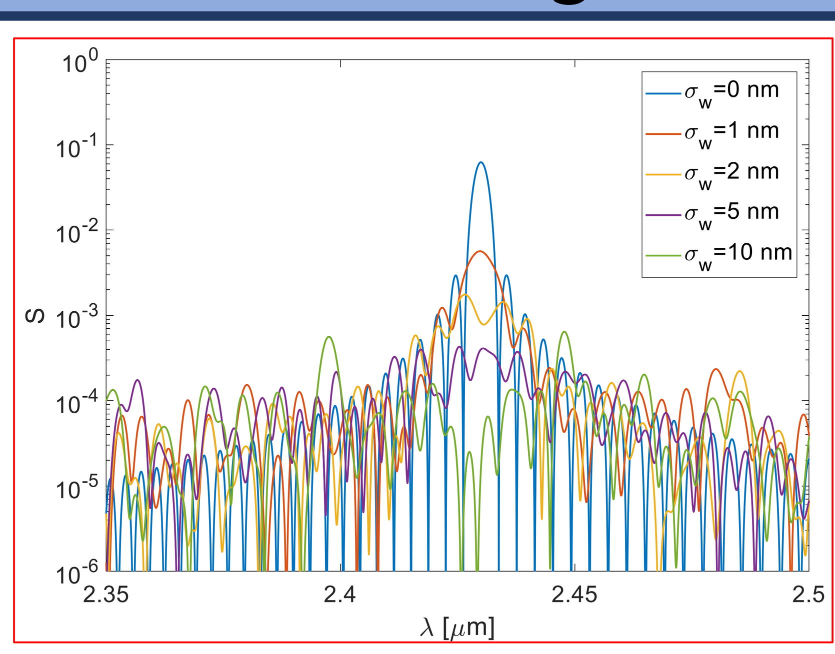
Modeling



Defects in the poling function:

In order to see the splitting of the peak an error > 50 nm is needed.

Not compatible with the resolution process

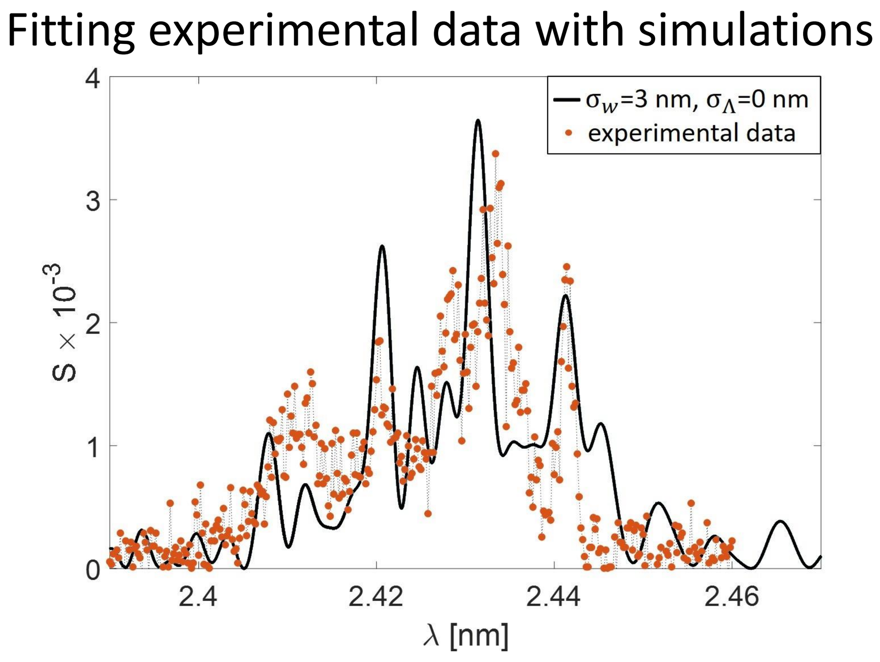


Defects in the width:

In order to see the splitting of the peak an error > 2 nm is needed.

Compatible with the resolution process

Fitting experimental data with simulations



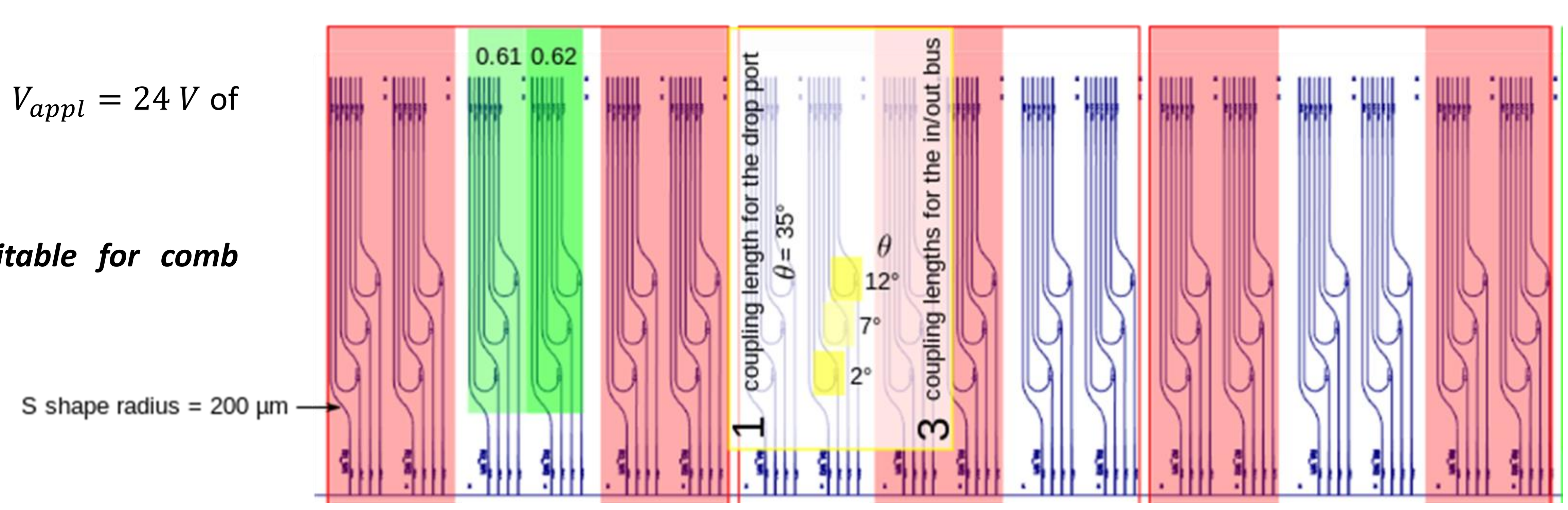
Conclusions

- Clear understanding of the process
- Possibility to extract the value of the effective $\chi^{(2)}$ for $V_{appl} = 24\,V$ of applied bias and $\sigma_w = 0\,nm$:

$$\chi^{(2)}_{eff} = 8{,}4 \pm 0{,}4\ {}^{pm}/_{V}$$

- ***Is possible to applied p-i-n junction to microrings suitable for comb generation***

Now we are testing some designs of microrings in order to find the best solution for a design of the chip



Fabrication related imperfections in the width of the waveguide cause the appearance of multiple peaks in the generation efficiency which spoil the overall SHG efficiency. However the large generation band can be exploited in comb engineering by widening the generation band and therefore the frequency comb.

Acknowledgements funding by MIUR through NEMO PRIN 2015 project