4-28-2023

Guided-Mode-Resonance as a Source of Entangled Photons

Henry Windish

Washington University in St. Louis, h.w.windish@wustl.edu

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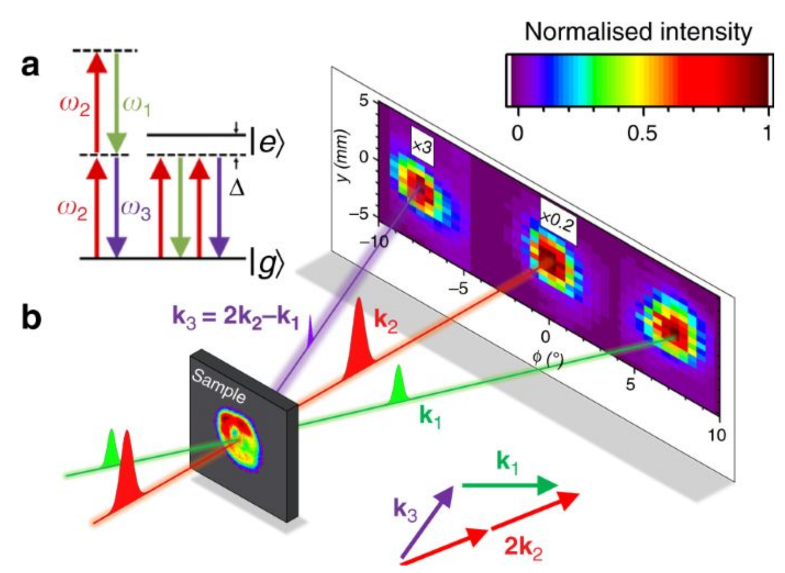
The Lawrence Lab

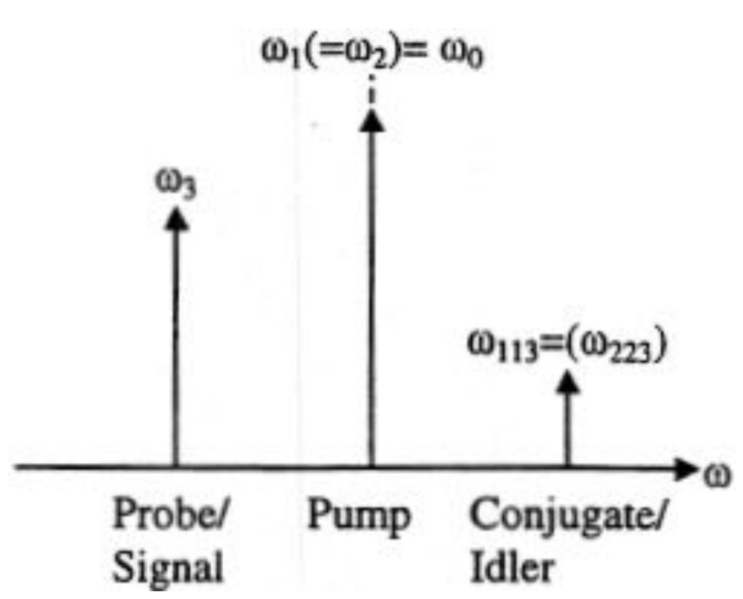
Spontaneous Four Wave Mixing



(Dessman)

Four wave mixing is a phenomenon in nonlinear optics where interactions between two input frequencies produce new two new frequencies. This interaction arises from the third-order nonlinearity of the medium.

I am using a variation of four wave mixing called degenerate four wave mixing. This is where the two input frequencies coincide, leading to the doubled input frequency producing resonances at two different frequencies.

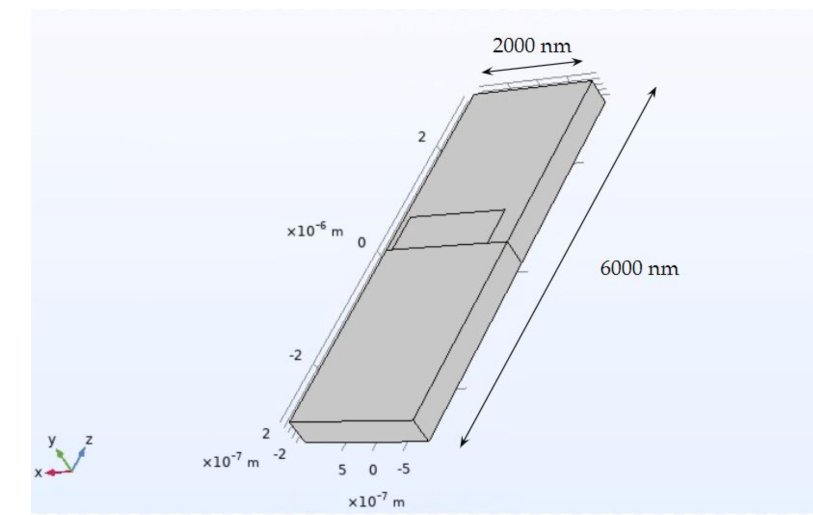


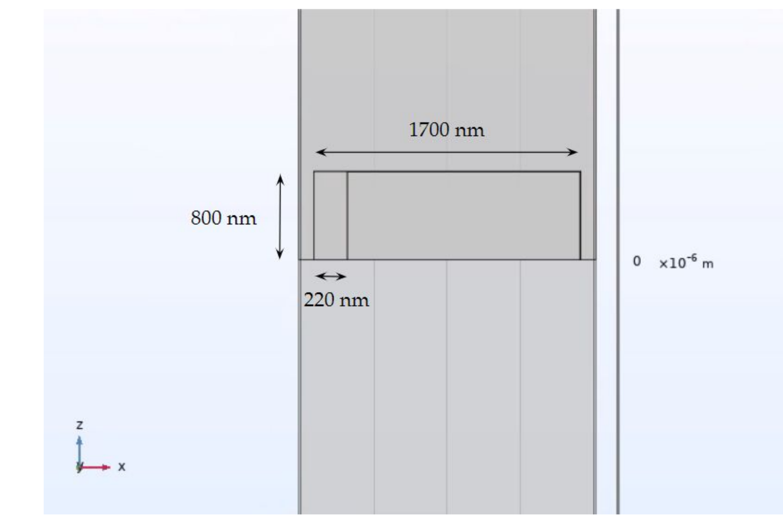
(Billington)

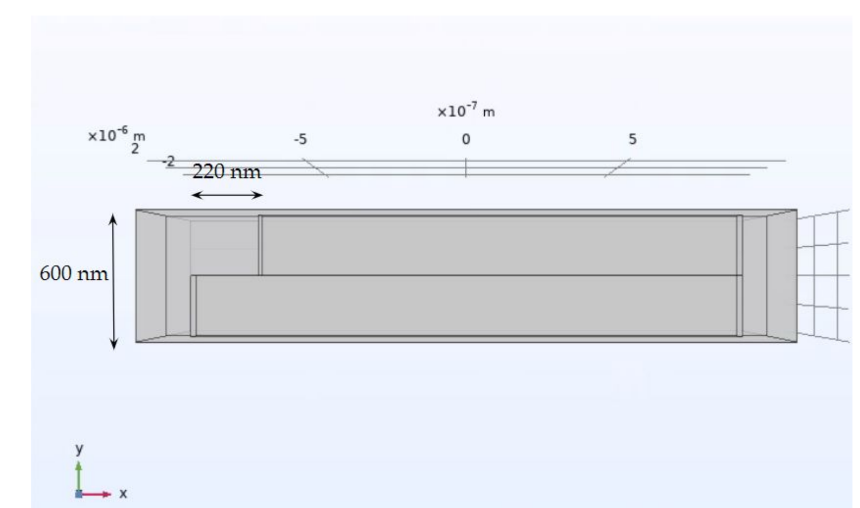
Looking to meet the quantum fluorescence condition where three resonances exist, following:
$\omega_1 + \omega_3 = 2 \times \omega_2$.

Light is fed into metasurface at the pump frequency, resulting in an outputted pair of photons at the signal and idler frequencies. This outputted pair has a chance to be an entangled or correlated photon pair.

Metasurface Design

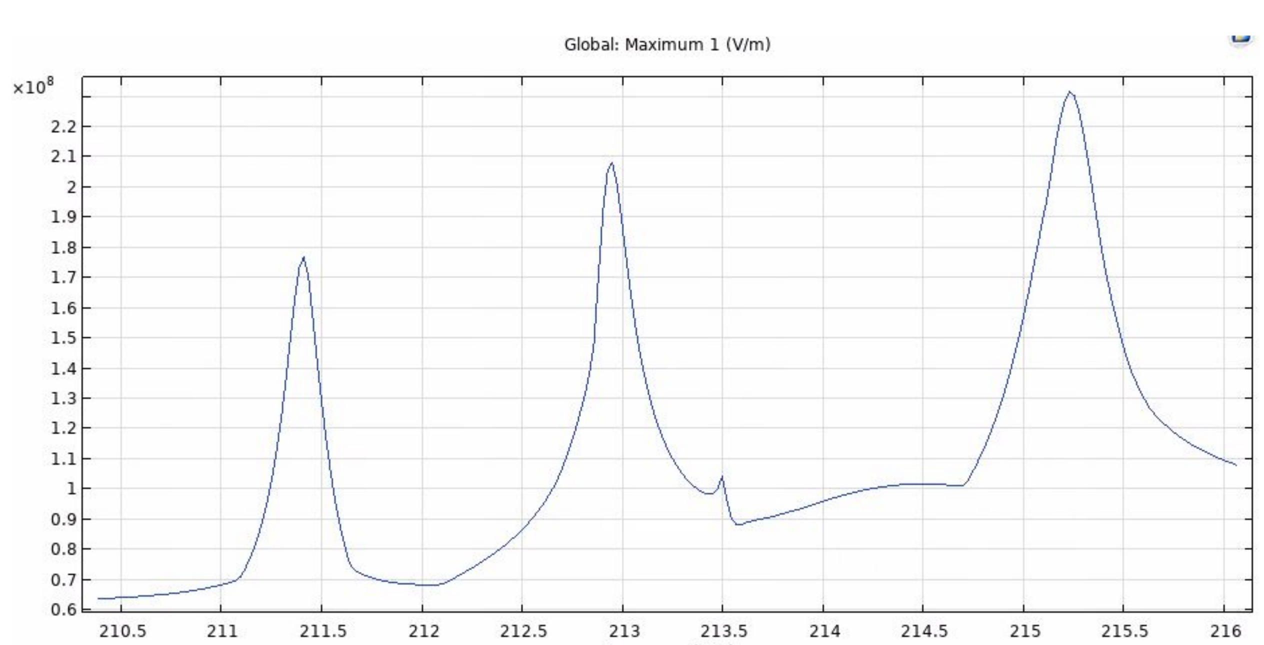




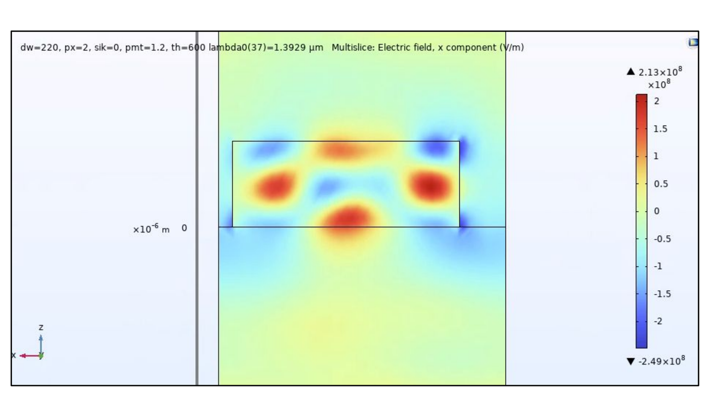


This design allows for the tuning of three (nearly) independent resonances. Featuring a 220 nm notch in the silicon, this is what creates the asymmetrical resonances within the metasurface. Tuning various parameters of the shape, such as notch depth, notch width, and period allows for tuning the modes.

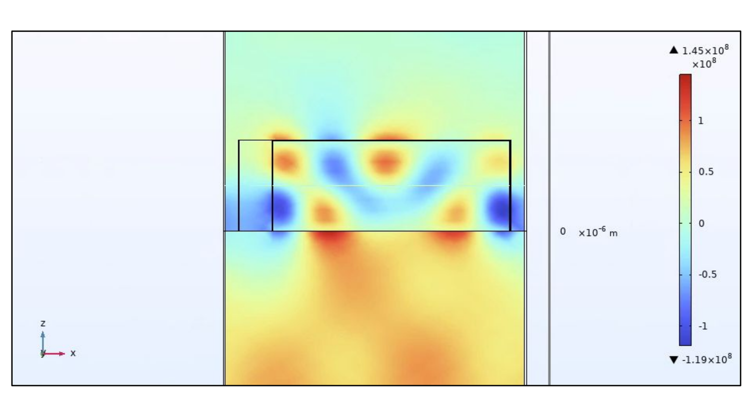
Resonances and Results



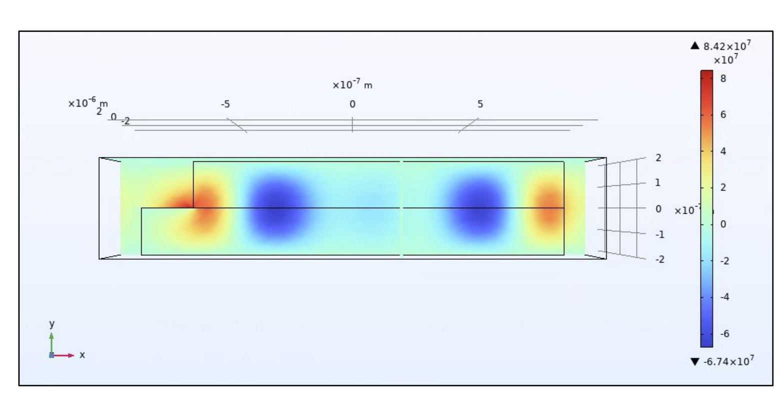
This design features resonances with peaks at 211.4 THz, 212.95 THz, and 215.25 Thz. The middles resonance peak differs from its ideal position by .75 THz. However, this point is still within the full width half max of the resonance. These resonances all have high Q. While that decreases the full width half max of each resonance, high Q is required to increase the photon pair generation rate.



Ex of Lowest Resonance



Ez of Middle Resonance



Ey of Highest Resonance

Other Considerations

Transmittance

Key:
Light Blue: Total Transmittance
Dark Blue: 0 0 Transmittance
Green: 0 1 Transmittance
Red: 0 -1 Transmittance

The dips in transmittance are quite shallow. Ideally, each of this dips would be much more extreme. From the transmittance order, we can see that the 0 1 and 0 -1 orders are interfering with the 0 0 order. To improve my design I need to to control the higher diffraction orders to be constructive with the 0 0 order.

Pair Generation

The pair generation rate for a microring resonator is shown below. This equation shows the importance of having high Q resonant modes.

$$R_{\rm PG} = (\gamma 2\pi R)^2 \left(\frac{Q v_g}{\pi \omega_p R}\right)^3 \frac{v_g}{4\pi R} P_p^2,$$

(Steiner)

Pair generation measures the rate at which photon pairs are created (typically in units of $1/\text{SmW}^2$). Pair generation rate is a function of resonance quality factor, effective mode area, and group velocity. I am currently working towards calculating the pair generation rate of my design.

Figure Citations:

Billington, R. "A Report on Four-Wave Mixing in Optical Fibre and its Metrological Applications." *National Physical Laboratory.* 1999. https://eprintspublications.npl.co.uk/1036/1/coem24.pdf

Dessmann, N., Le, N.H., Eless, V. *et al.* "Highly efficient THz four-wave mixing in doped silicon." *Light Sci Appl* 10, 71 (2021). https://doi.org/10.1038/s41377-021-00509-6

Steiner, Trevor J. "Ultrabright Entangled-Photon-Pair Generation from an Al Ga As-On-Insulator Microring Resonator." *PRX Quantum.* 4 March 2021. https://doi.org/10.1103/PRXQuantum.2.010337