THE UNIVERSITY OF TEXAS AT AUSTIN

WHAT STARTS HERE CHANGES THE WORLD

National Nanotechnology Coordinated Infrastructure

NSF

"Nonlinear optical metasurfaces with giant second harmonic response"

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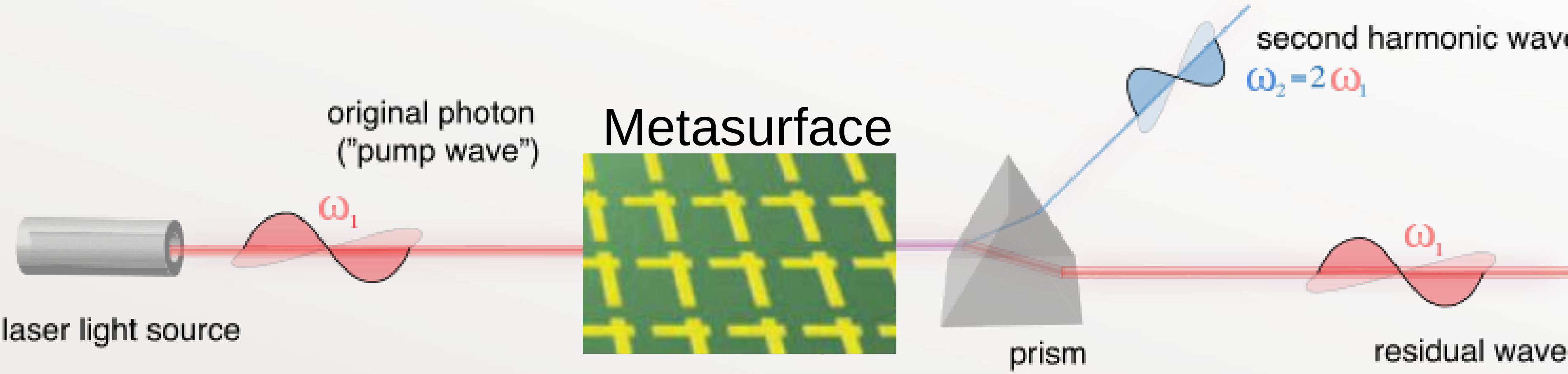
Project Goals:

- Design and simulate new T shape nano-resonators optimized for a new multi-quantum well (MQW) structure and wavelength of light, 6.7 µm.
- Design new original antenna structures.
- Calculating the $\chi_{yxx}^{(2)}$ for the resonator structures.
- Use the clean room equipment to precisely etch antenna designs into the MQW structure.
- Test the metamaterials using a wideband infrared laser for analysis of second harmonic generation.
- Design metasurface to work in transmission.

Background: Second Harmonic Generation (SHG)

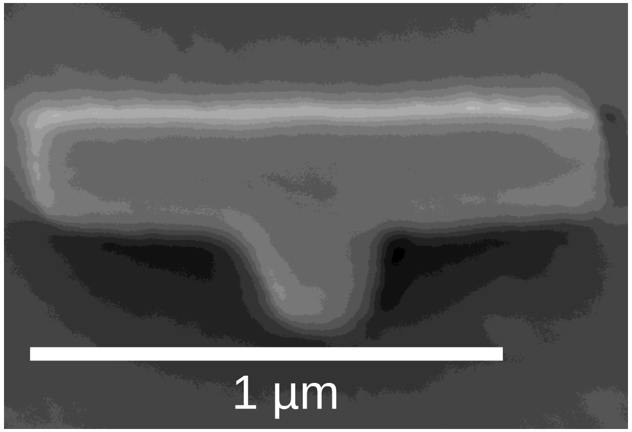


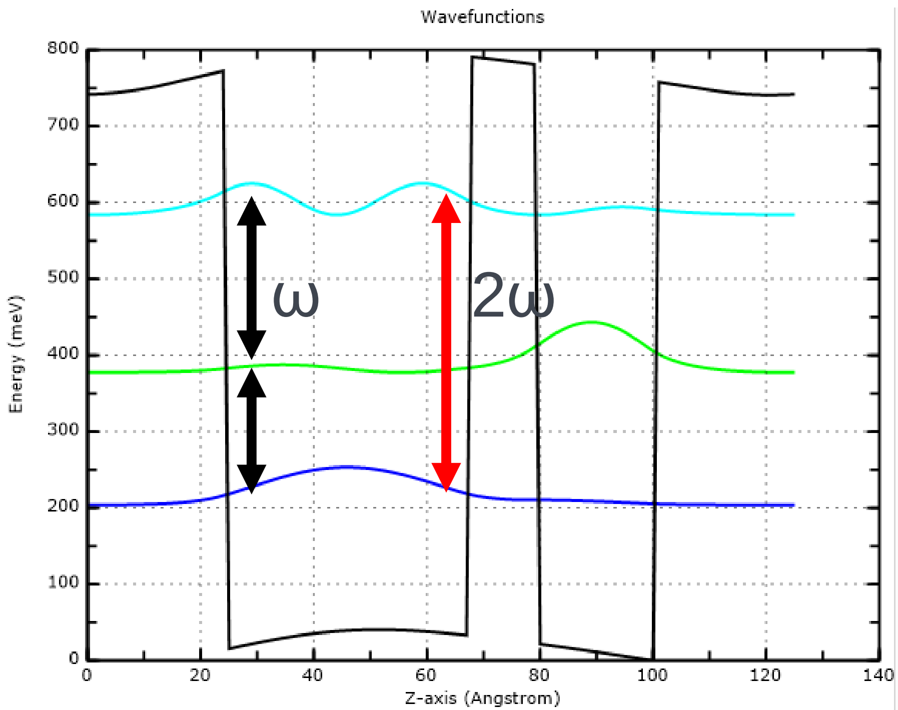
Current bulk crystals require careful optical axis alignment and advanced precision for phase matching of SHG.

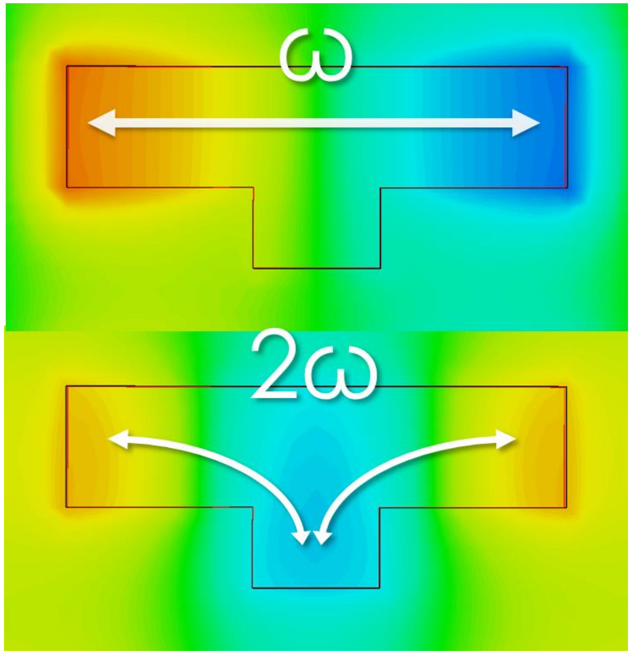
Our material is sub-wavelength, while providing a nonlinear susceptibility at least 3 orders of magnitude greater than current natural crystals.

Background: Second Harmonic Generation (SHG)

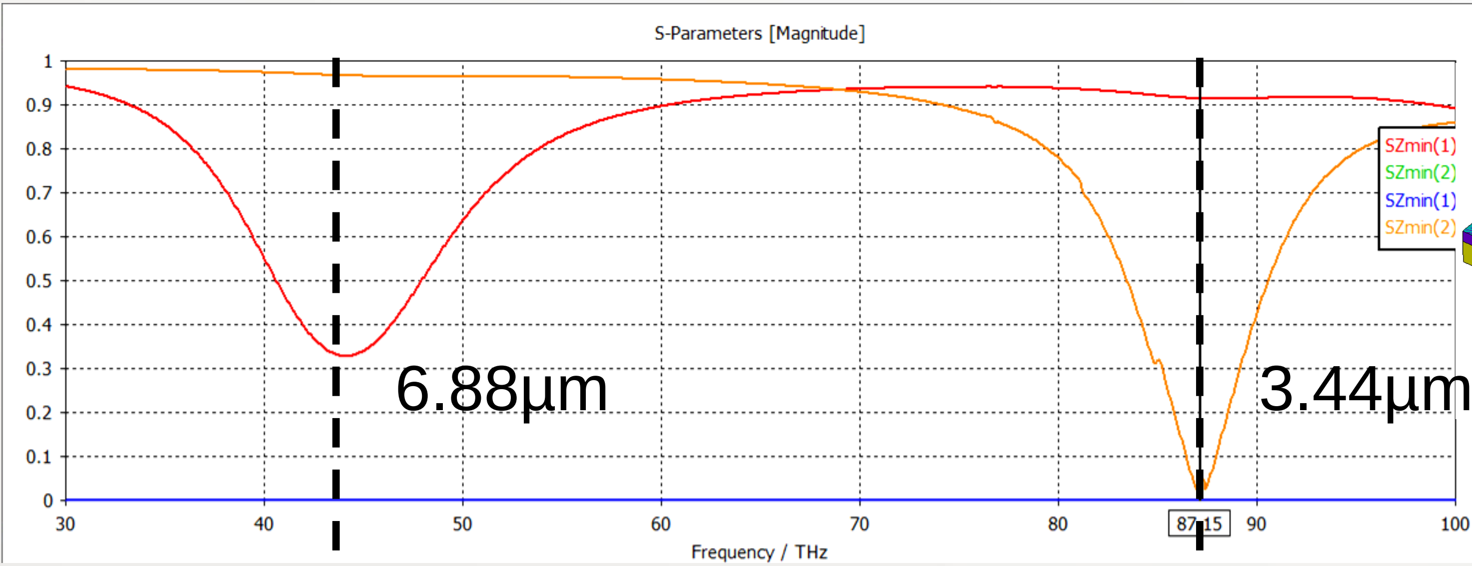
$$\chi^{(2)}_{ijk} = \chi^{(2)}_{\mathrm{MQW},zzz}\left[\frac{\int_{\mathrm{UC}} \xi_i^{2\omega}(x,y,z)\,\xi_j^{\omega}(x,y,z)\,\xi_k^{\omega}(x,y,z)\,\mathrm{d}V}{V}\right]$$

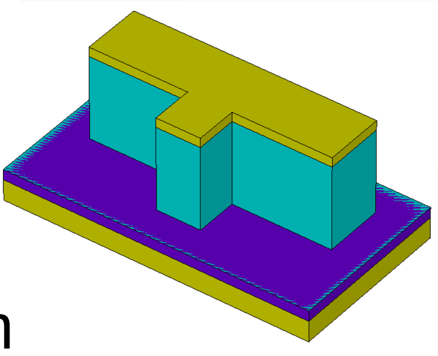


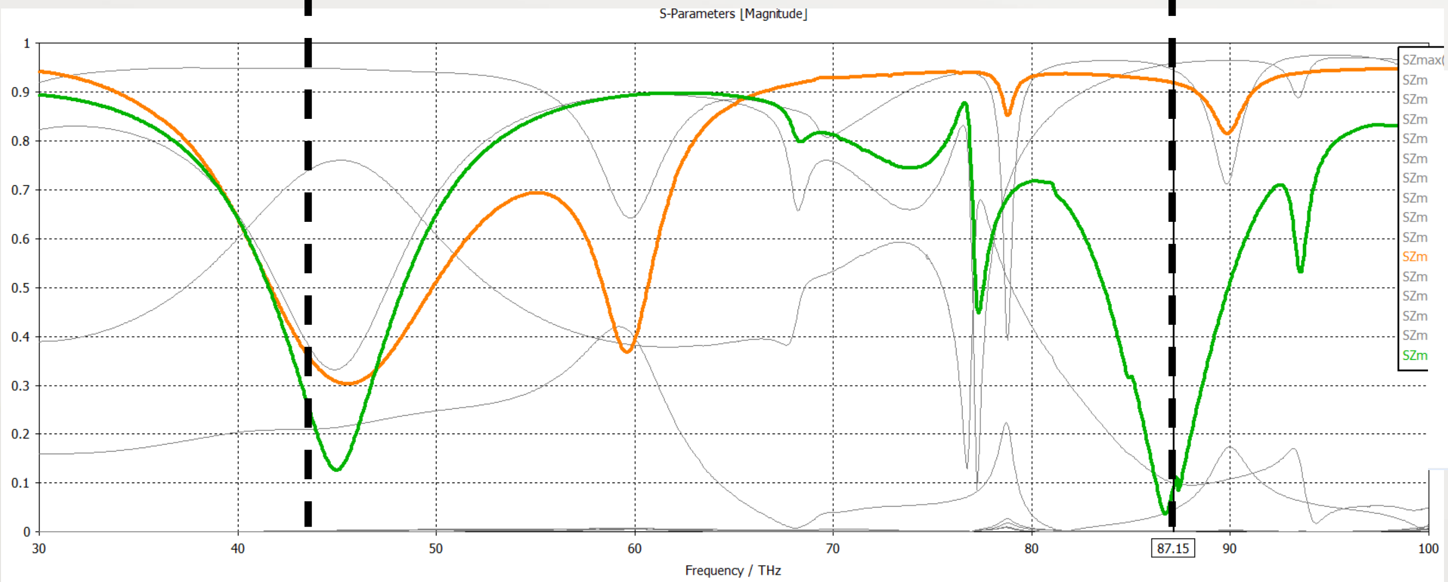


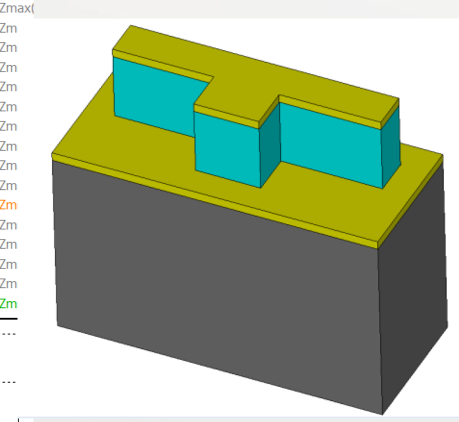


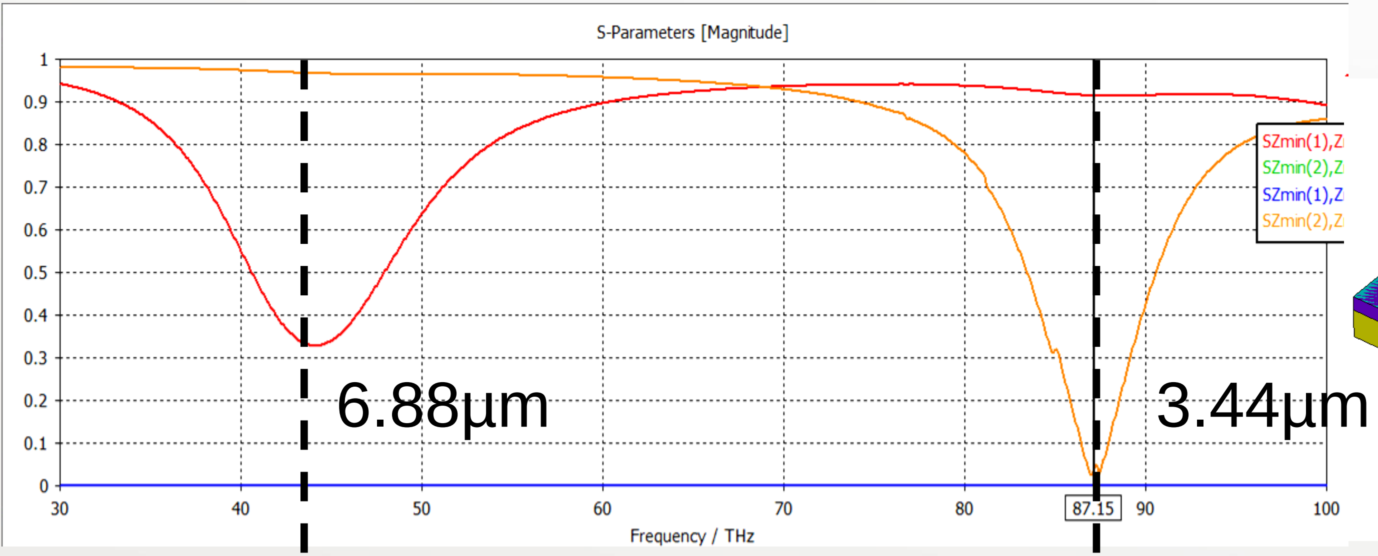
Simulation software: CST Suite







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0.6
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0.3
0.2
0.1
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40
50
60
70
80
87.15
90
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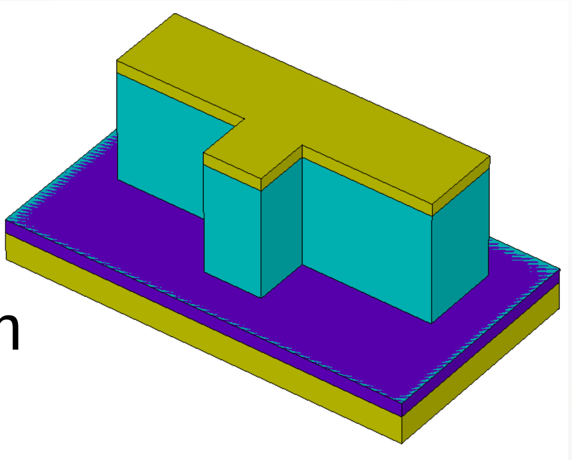
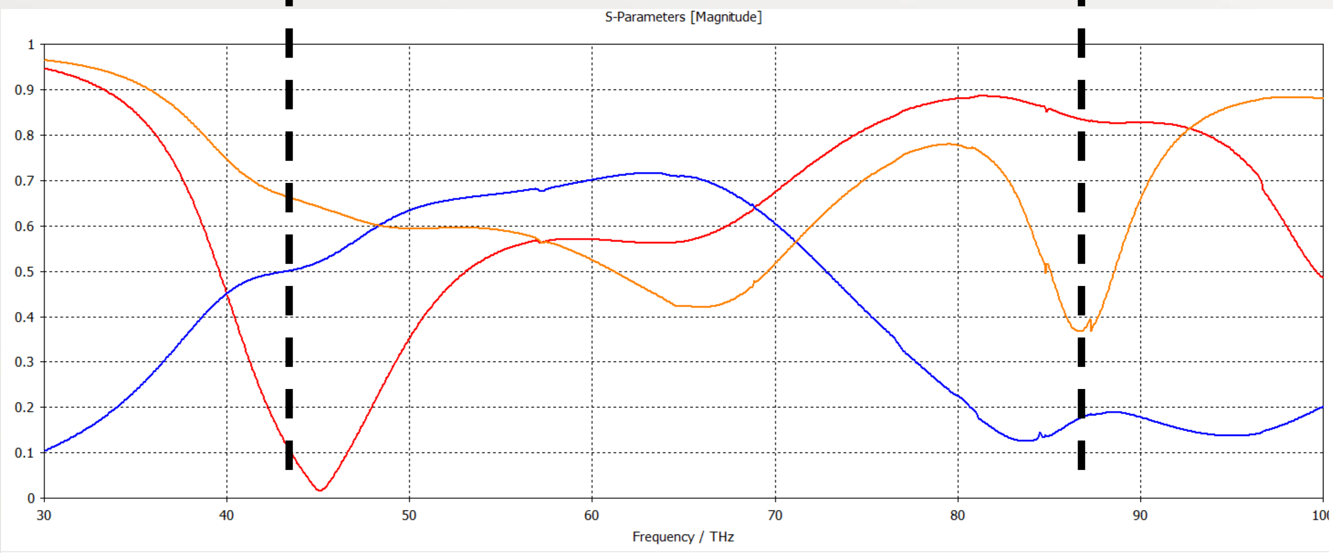
Frequency / THz
6.88µm
3.44µm
SZmin(1),Z
SZmin(2),Z
SZmin(1),Z
SZmin(2),Z

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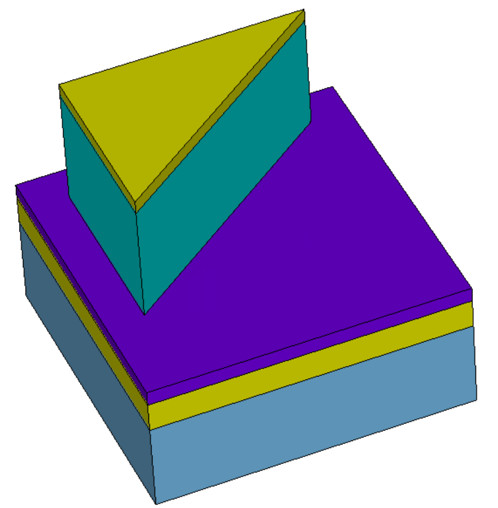
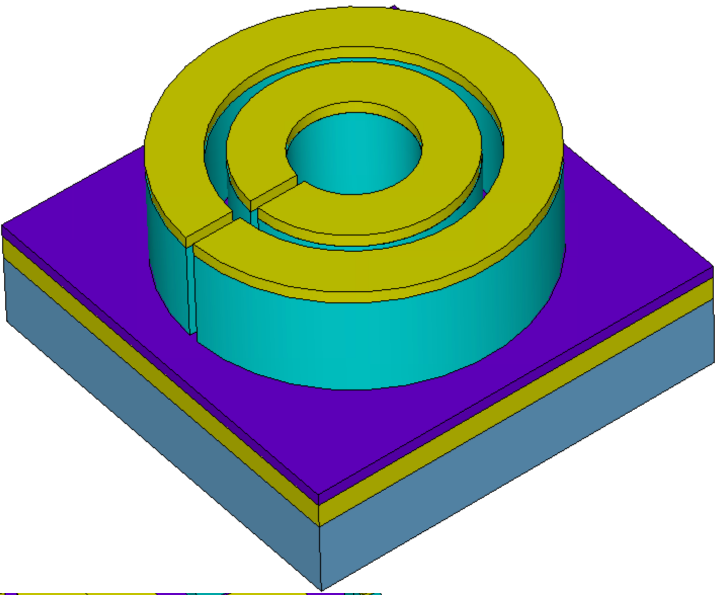
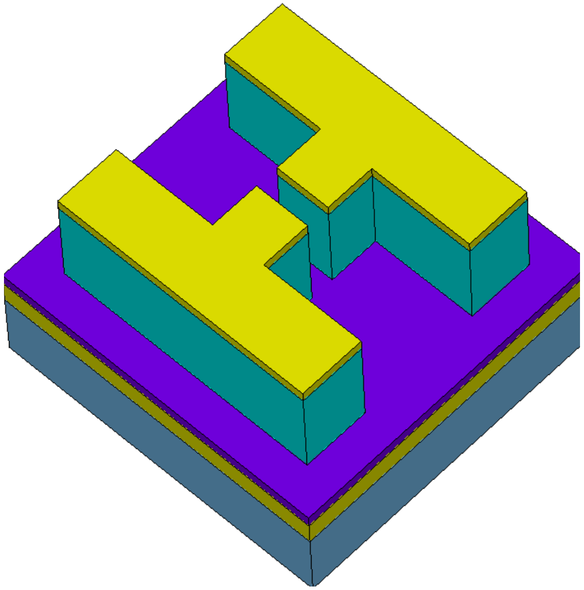
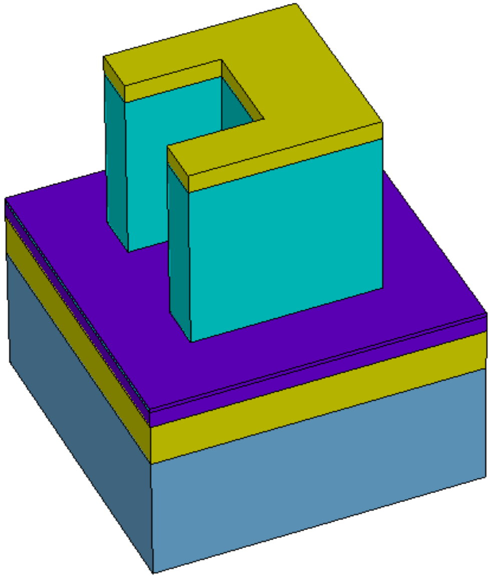
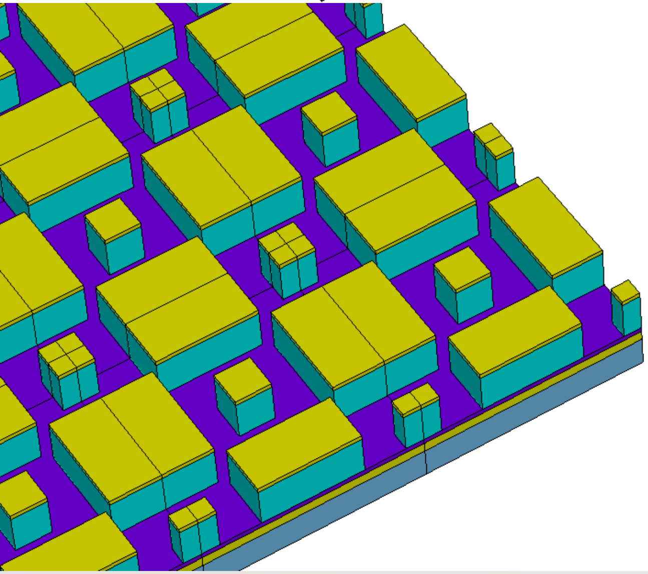
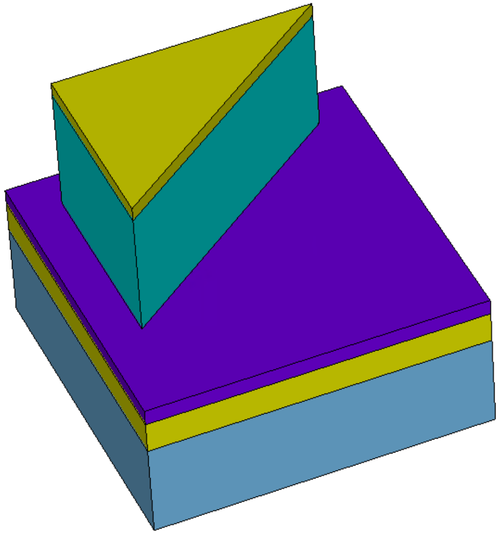
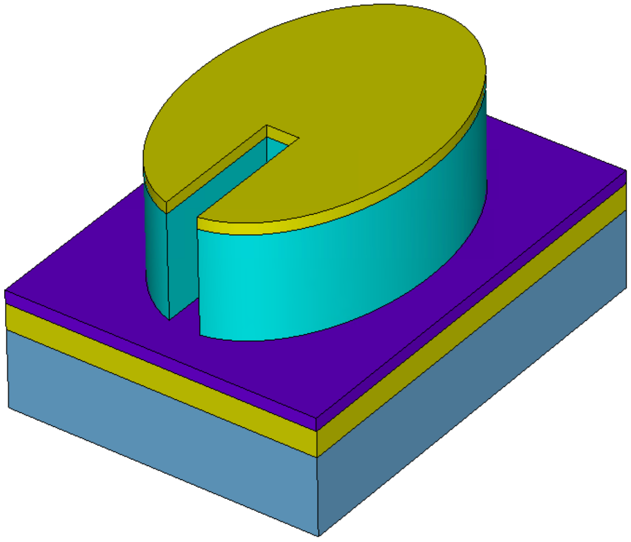
Frequency / THz



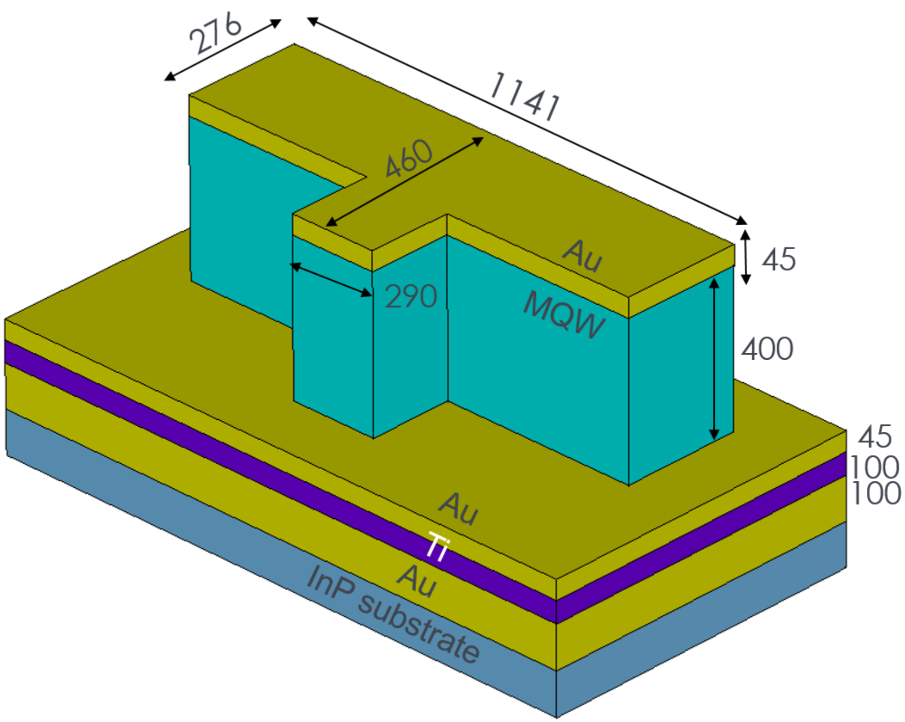
Examples of failed simulation designs:

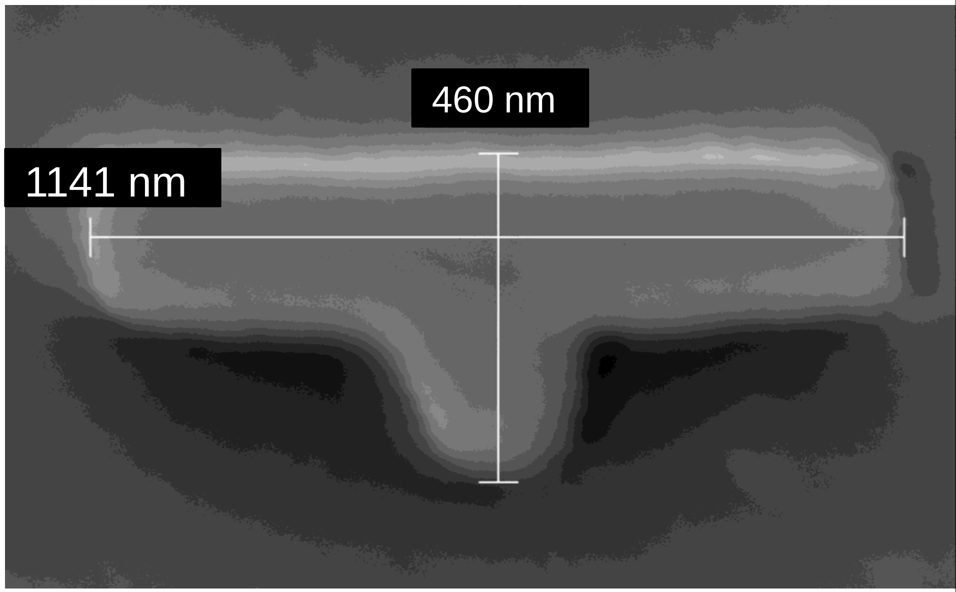







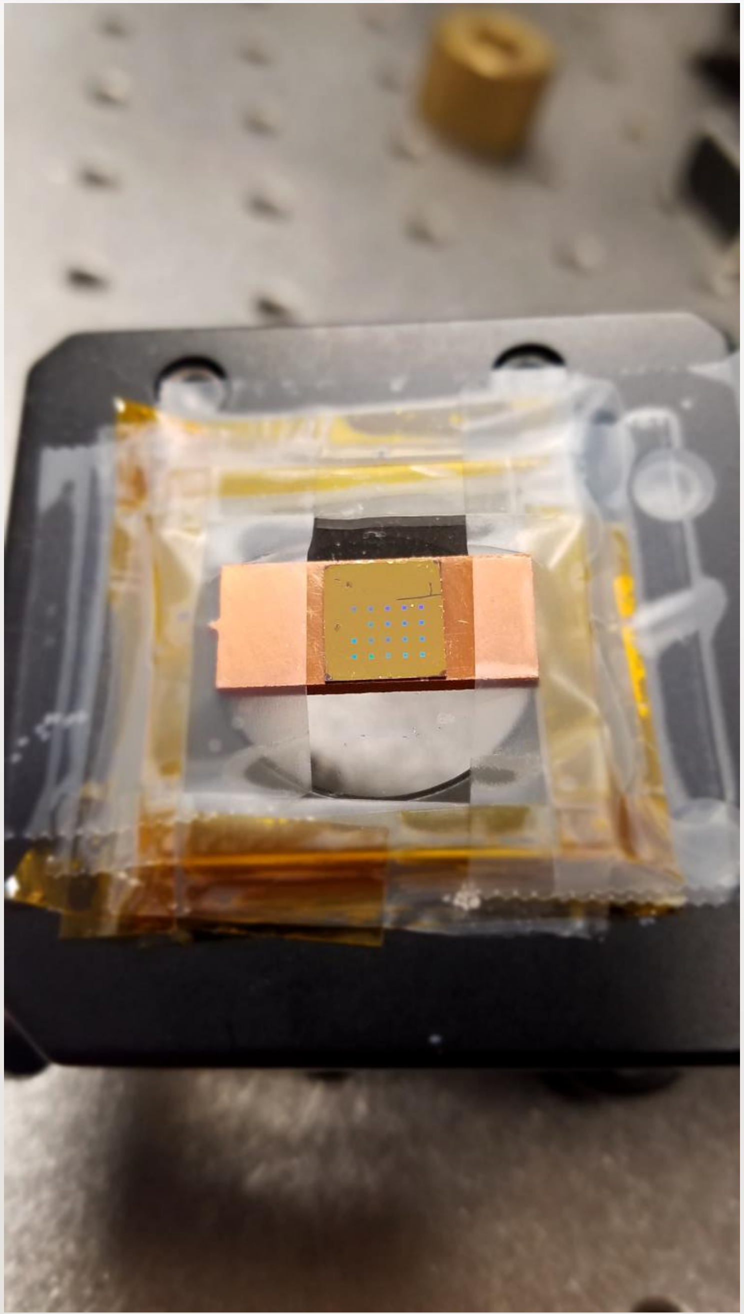
Antenna design:

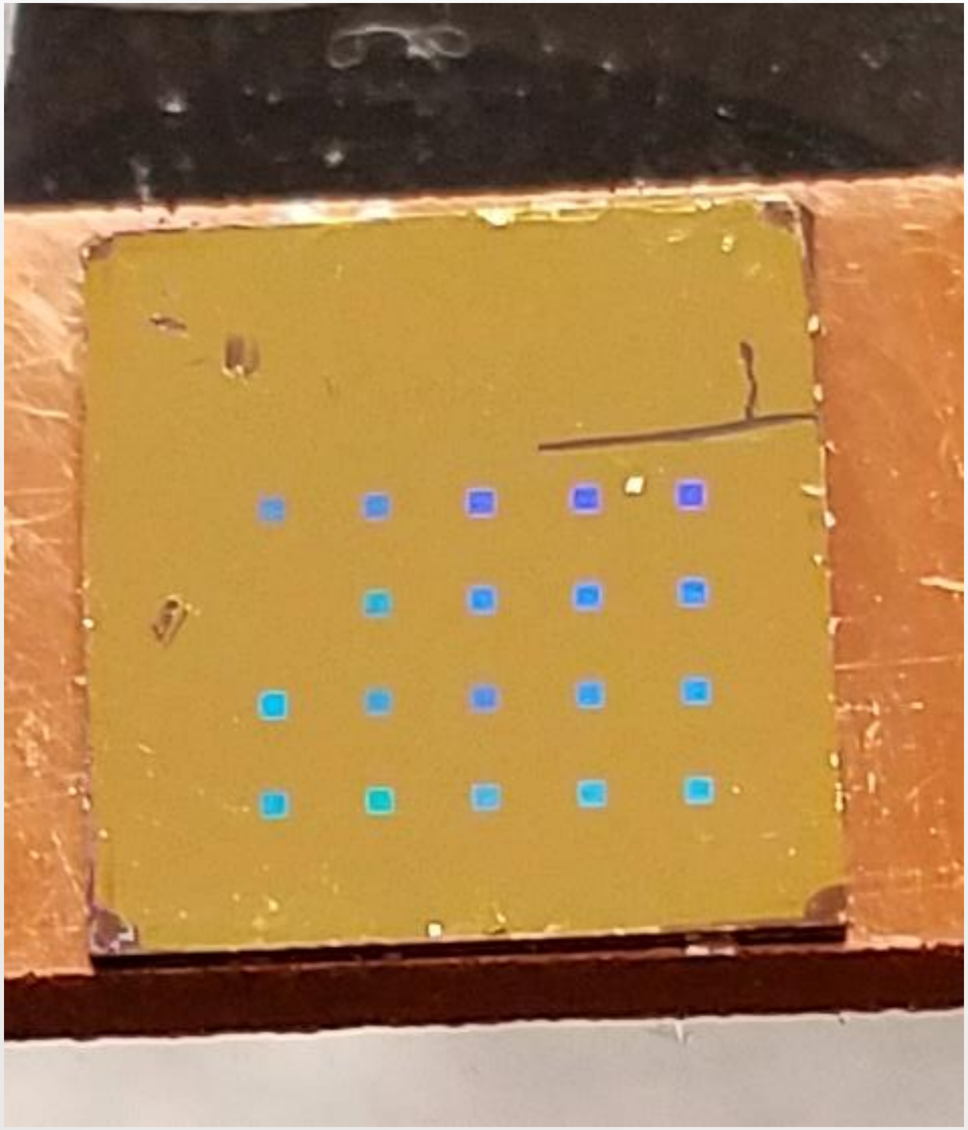
$$Overlap = \left[\frac{\int_{UC} \xi_i^{2\omega}(x,y,z)\xi_j^{\omega}(x,y,z)\xi_k^{\omega}(x,y,z)dV}{V} \right]$$

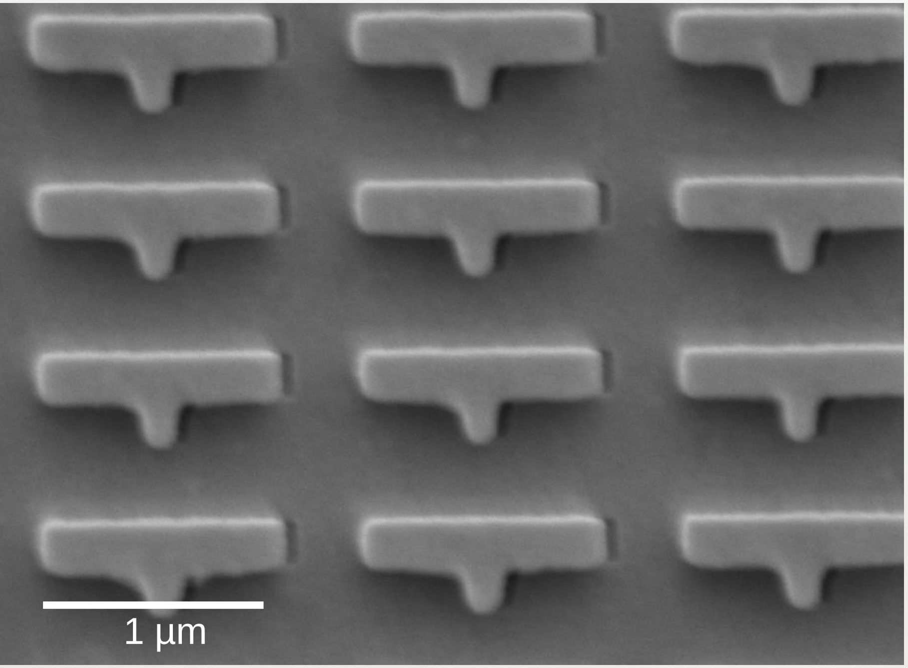
~2.87

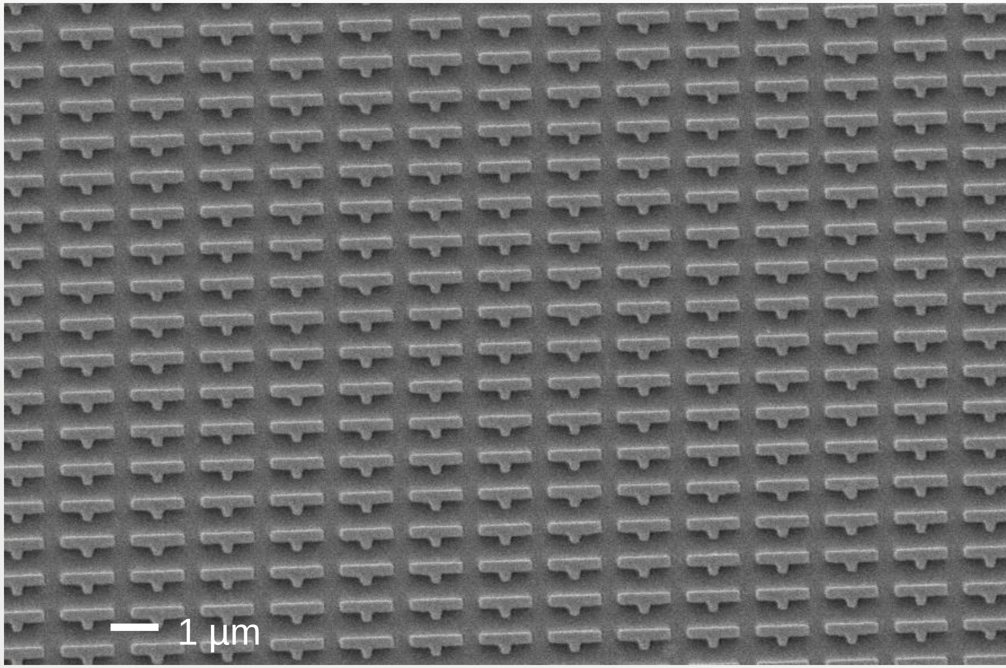




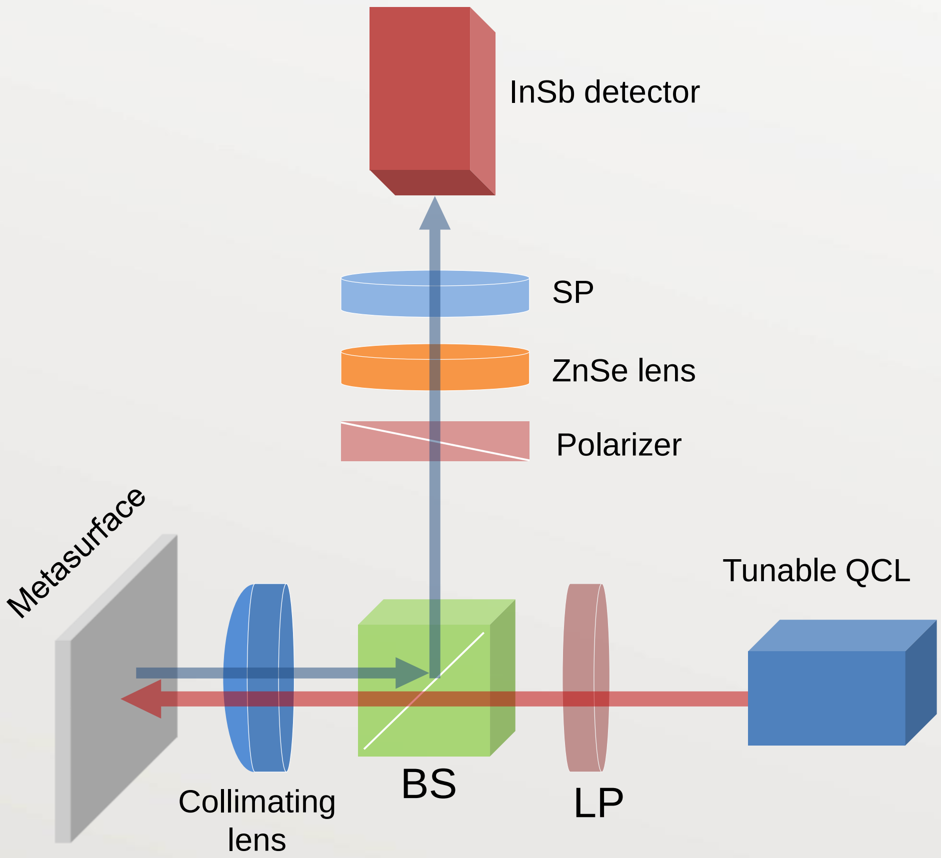


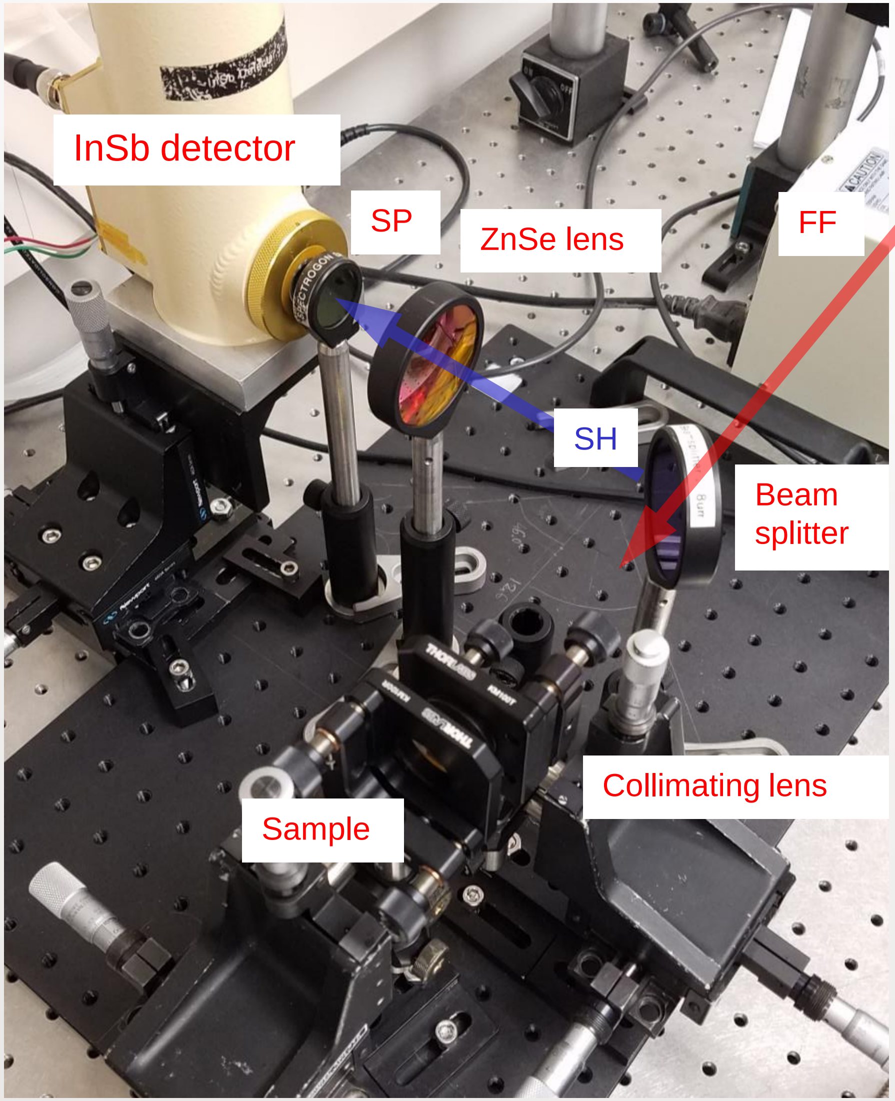



1 µm


1 µm

Experimental setup:



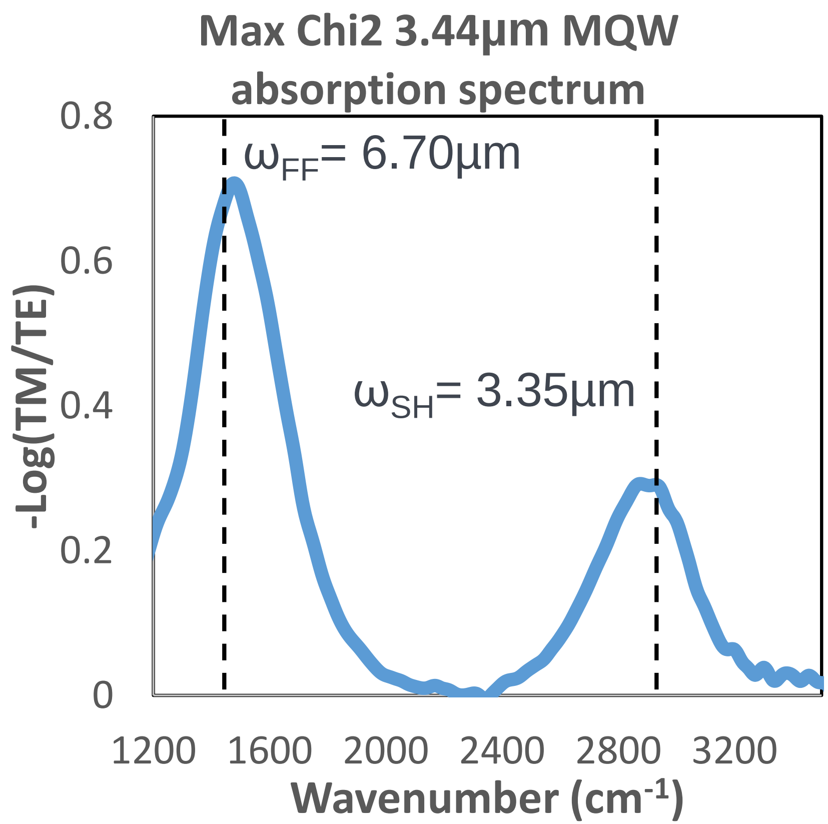


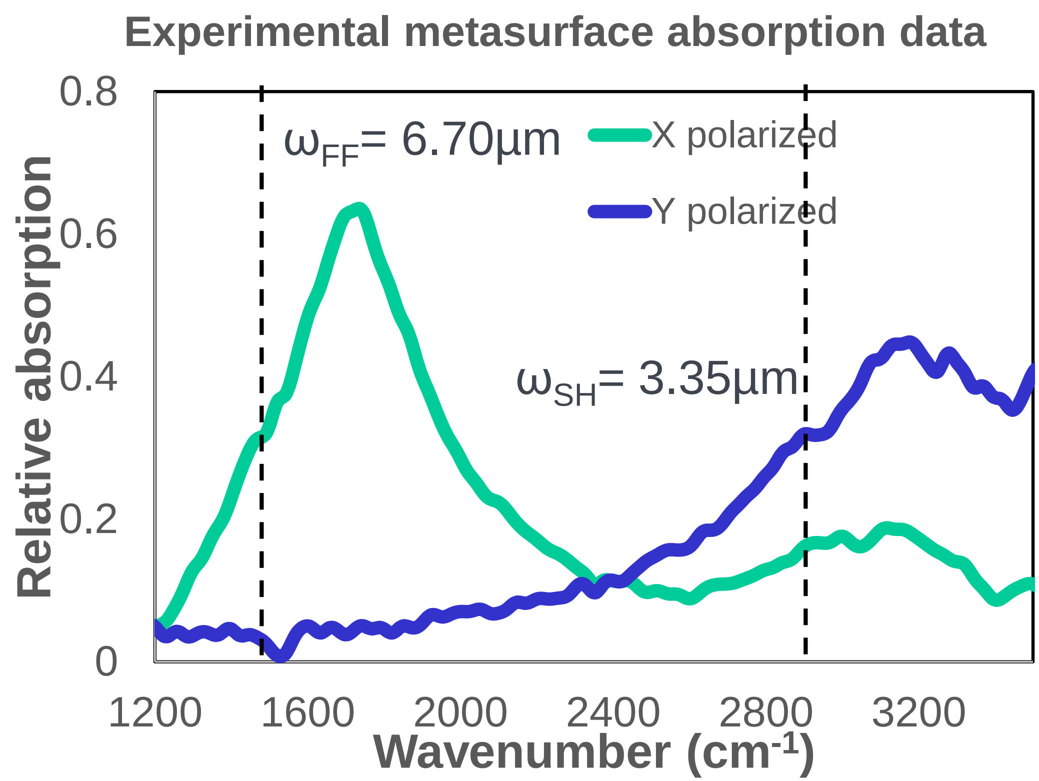
SHG metasurface 3.44μm Max Chi2:

$$\chi_{ijk}^{(2)} = \chi_{\mathrm{MQW},zzz}^{(2)} \left[\frac{\int_{\mathrm{UC}} \xi_i^{2\omega}(x,y,z)\xi_j^{\omega}(x,y,z)\xi_k^{\omega}(x,y,z)\mathrm{d}V}{V} \right]$$

Engineered MQW (~47nm/V)

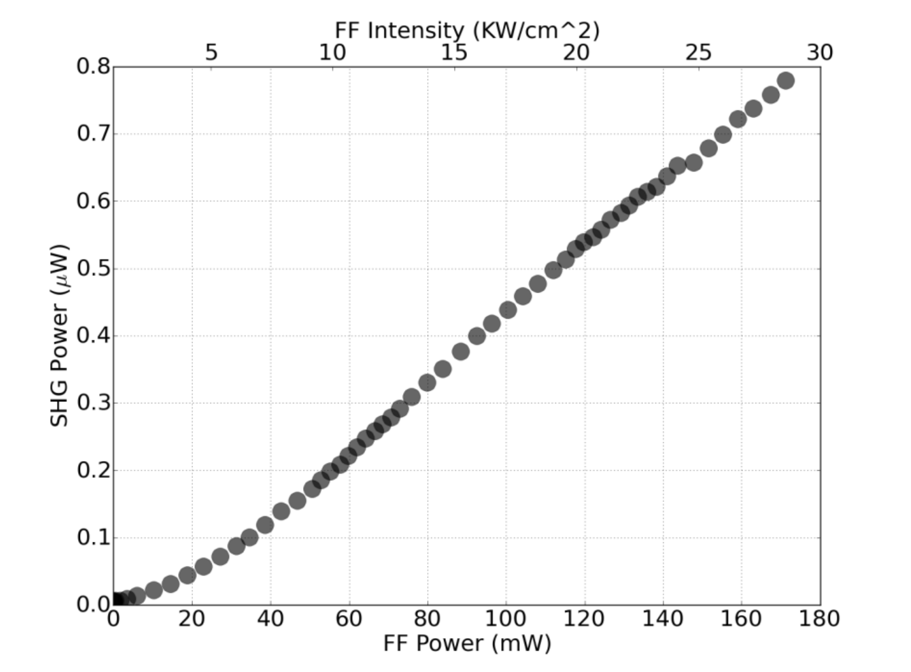
Spatial Overlap Integral (~1.21nm/V)



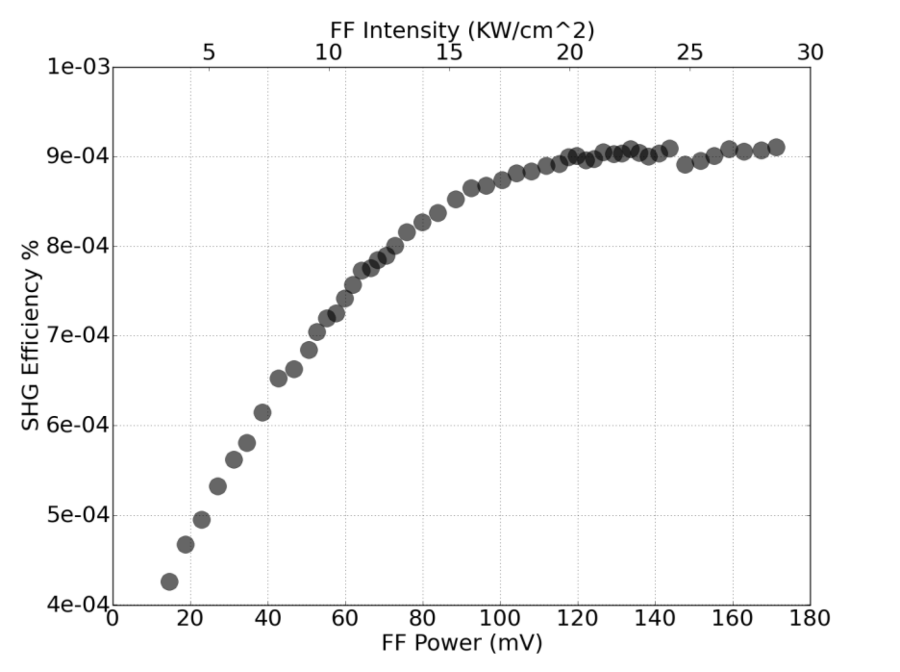


Experimental results:

Second harmonic power vs. fundamental frequency power



SHG efficiency vs. FF pump power



Conclusion:

- Our metamaterial successfully demonstrates second harmonic generation from incident 6.7μm to 3.35μm light
- Achieved ~10^{-3}% efficiency for SHG
- Calculated an effective $\chi_{yxx}^{(2)}$ of 1.21
- Removal of Au ground plane could make transmission mode possible and make it a much more practical optical element

Special thanks to:

NSF

NNCI

PI: Mikhail Belkin

Mentor: Nishant Nookala

Bibliography:

J. Lee, N. Nookala, J. S. Gomez-Diaz, M. Tymchenko, F. Demmerle, G. Boehm, M. Amann, A. Alù, and M. A. Belkin. “Ultrathin second-harmonic metasurfaces with record-high nonlinear optical response,” Adv. Optical Materials (2016).

J. Lee, M. Tymchenko, C. Argyropoulos, P.-Y. Chen, F. Lu, F. Bemmerle, G. Boehm, M.-C. Amann, A. Alù, and M. A. Belkin, “Giant nonlinear response from plasmonic metasurfaces coupled to intersubband transitions,” Nature **511**, 65-69 (2014).

Image: https://commons.wikimedia.org/wiki/File:Second_Harmonic_Generation.svg