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Saturation-Limited Second Harmonic Generation in a Quantum Well-Metasurface Coupled System

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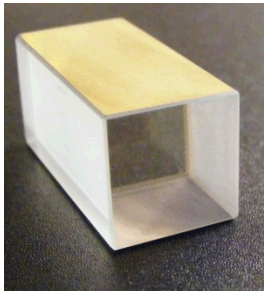
Second Harmonic Generation

Conventional method:

- macroscopic nonlinear crystal ($BBO, LiNbO_3, \ldots$)
- Low efficiency → long path length → **phase matching is a problem**



Other possibilities exist…

Outline

- Intersubband transitions in quantum-wells:
  - giant $\chi^{(2)}$ but only in z direction
- Metasurfaces:
  - fully engineerable resonances
  - Field enhancement
- Design and fabrication
- Power and frequency dependence
- Polarization separation

Intersubband Transitions in Quantum-Wells

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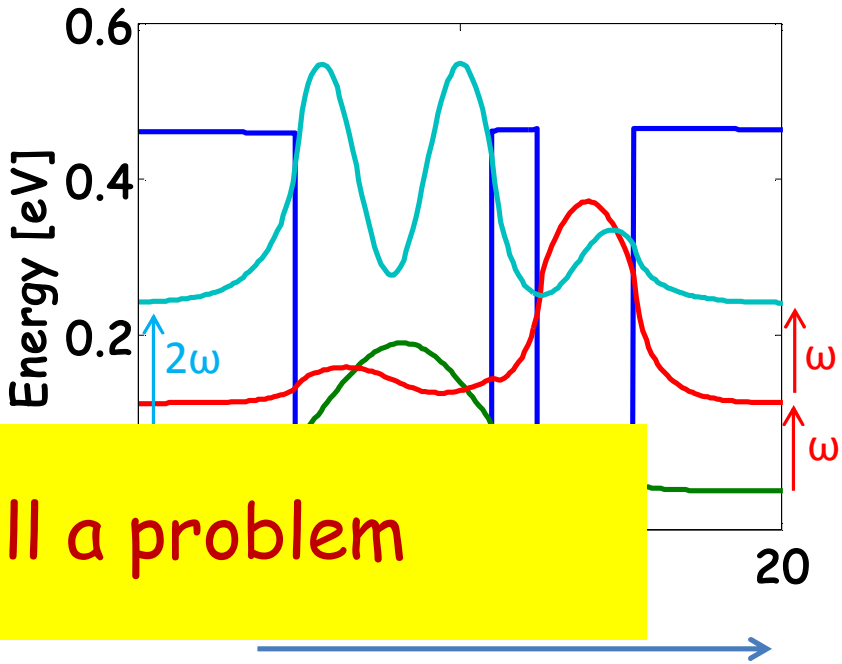
Properly designed ISTs exhibit very high $\chi^{(2)}$

~250 nm/V vs.

1C



Phase matching still a problem

The Problem: accessing transitions requires (photon E-field) in *Z* direction

Standard solution: oblique incidence excitation

F. Capasso, C. Sirtori, and A.Y. Cho, IEEE J. Quantum Electron. **30**, 1313 (1994)

Nanoresonators Enhance the Fields

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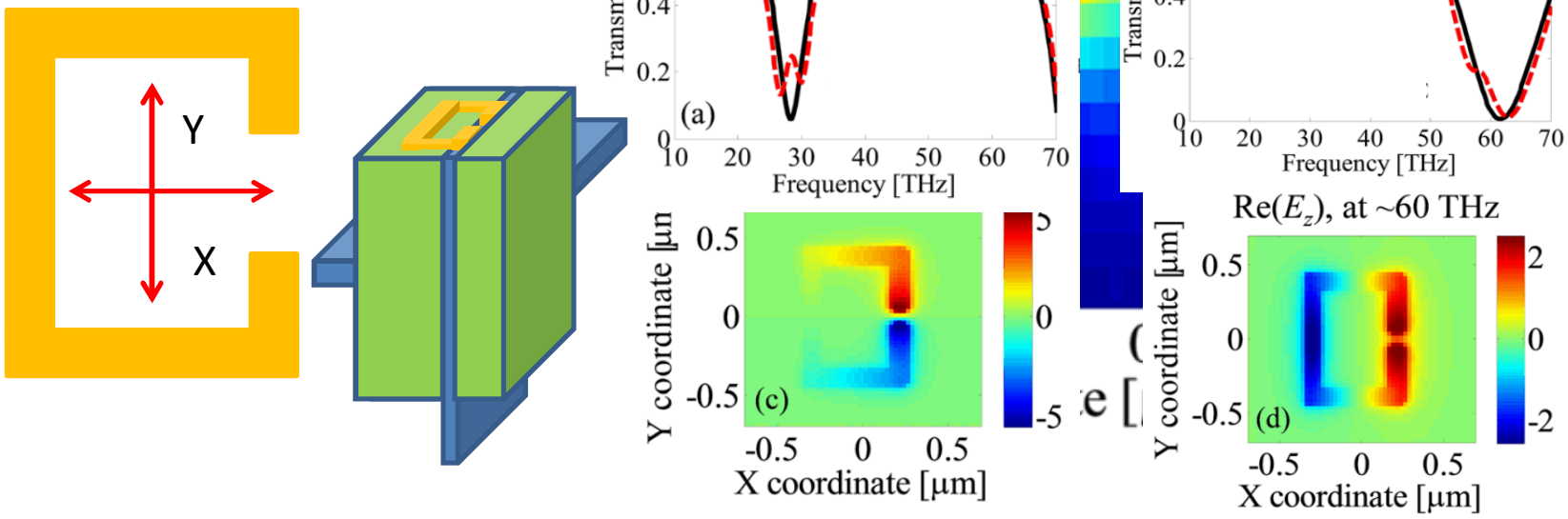
- Metallic nanoresonators **have** E_z in near-field for normal incidence



- Designed to have two resonances in FF and SH in cross polarizations
- Enhances fields by up to 5 times

S. Campione et al. *Appl. Phys. Lett.* **104**, 131104 (2014).

Design and fabrication

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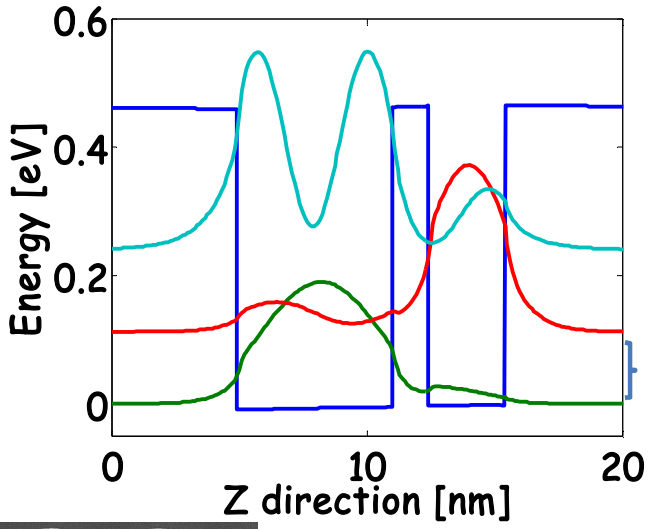
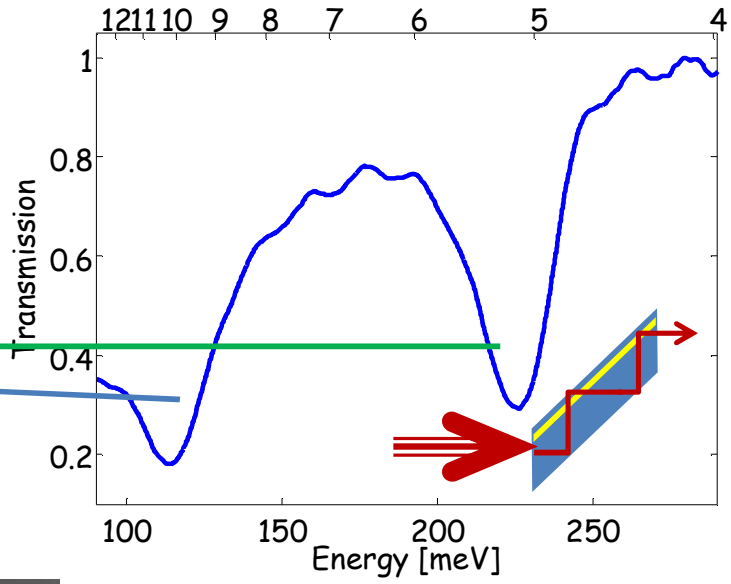
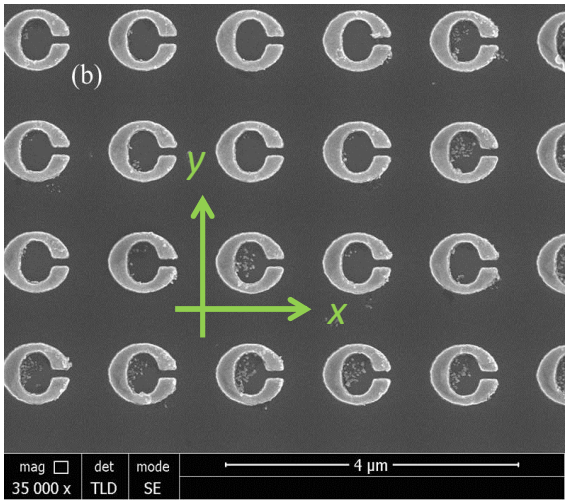
QW designed for 10μm → 5μm SHG, based on InGas/AlInAs system

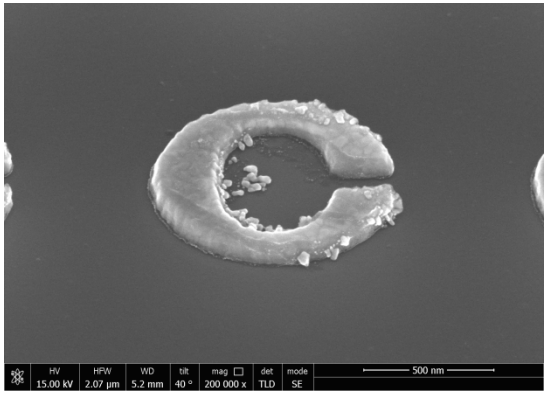
$$\chi^{(2)} \propto N \cdot z_{12} z_{23} z_{13}$$

$$z_{ij} \propto \frac{\langle \Psi_i | \vec{R} | \Psi_j \rangle}{E_j - E_i}$$

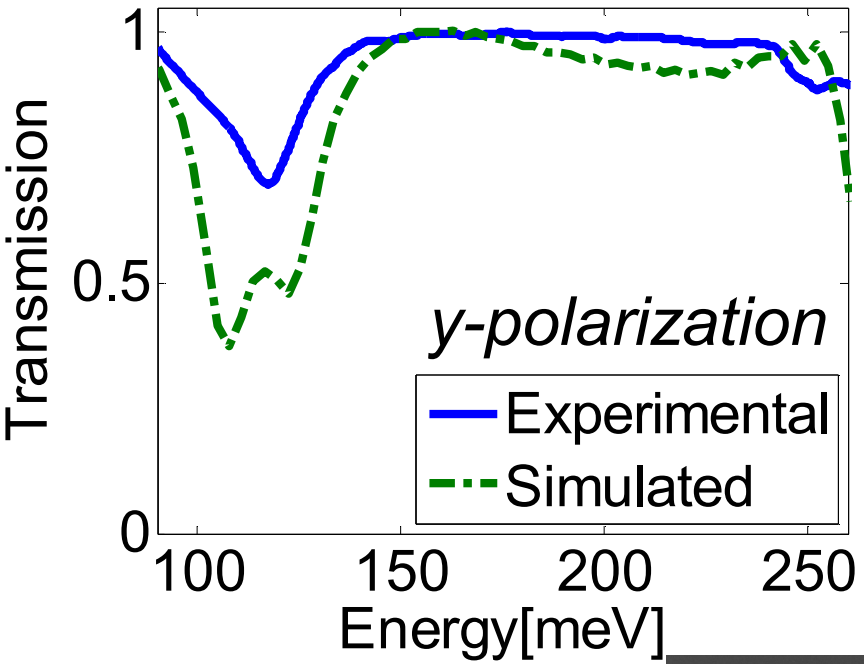


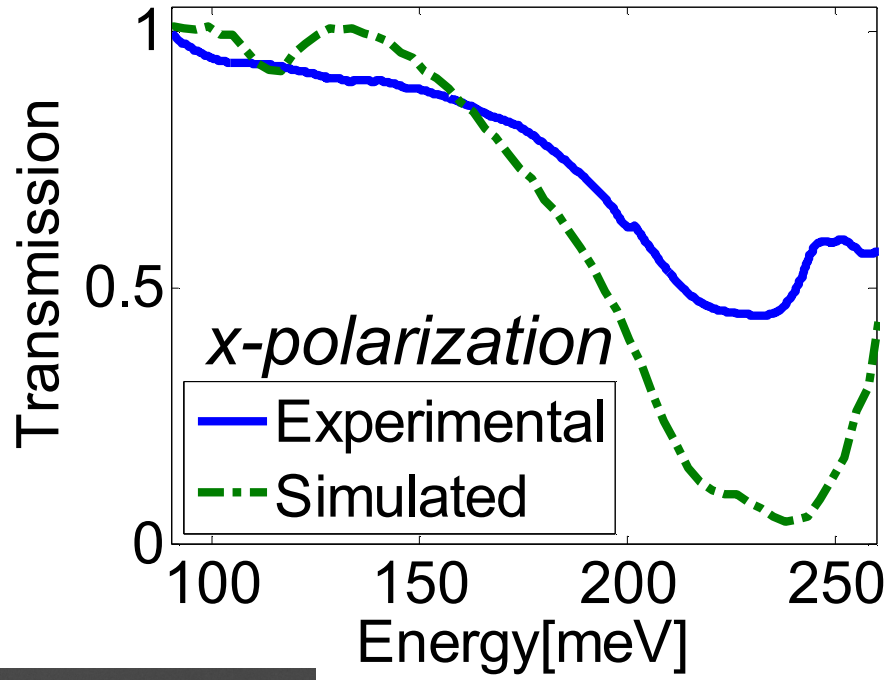


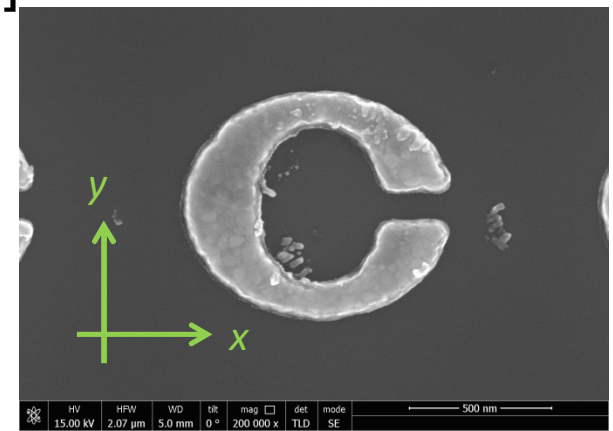




Linear Transmission







Power and Frequency Dependence

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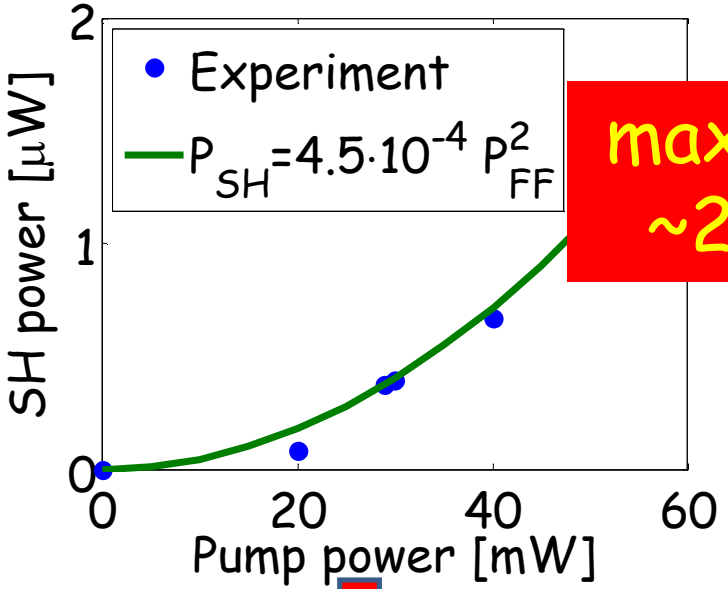
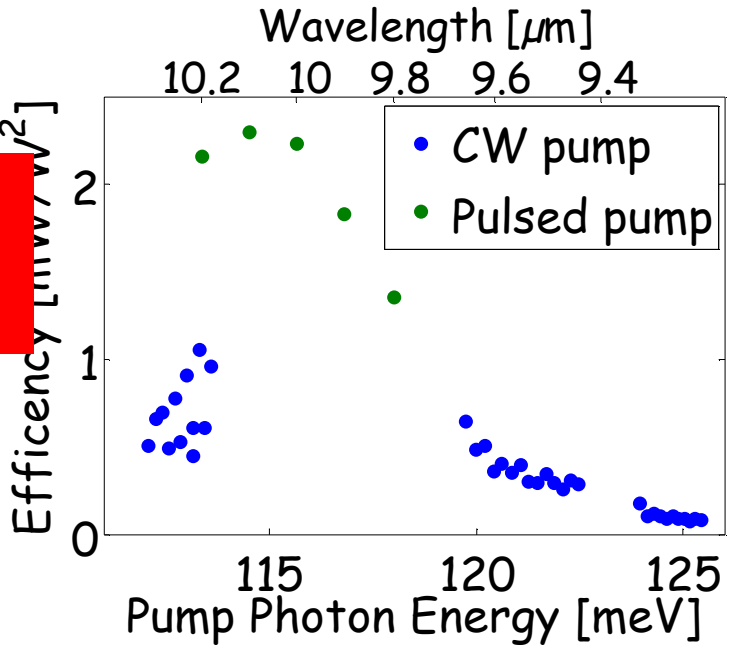
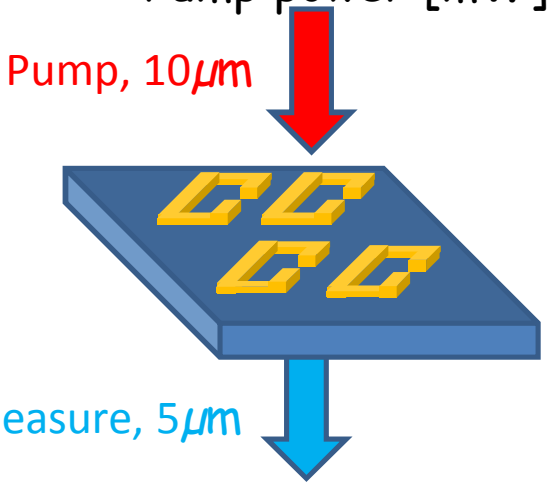
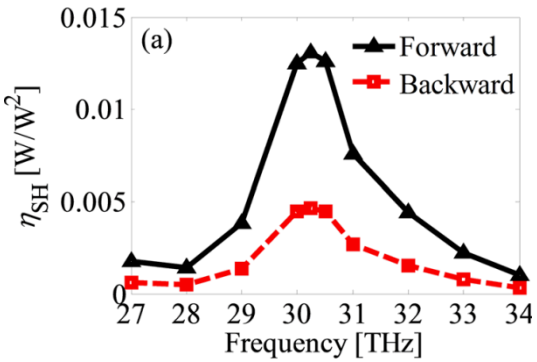
Pump is CW CO_2 laser



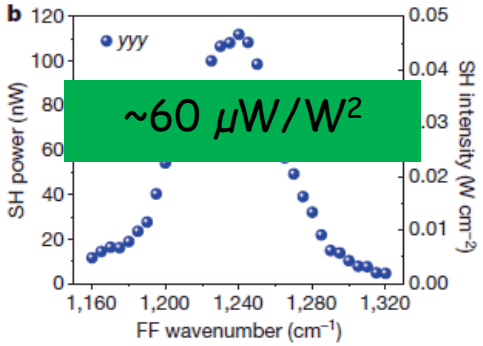
max efficiency: ~2.3 mW/W²







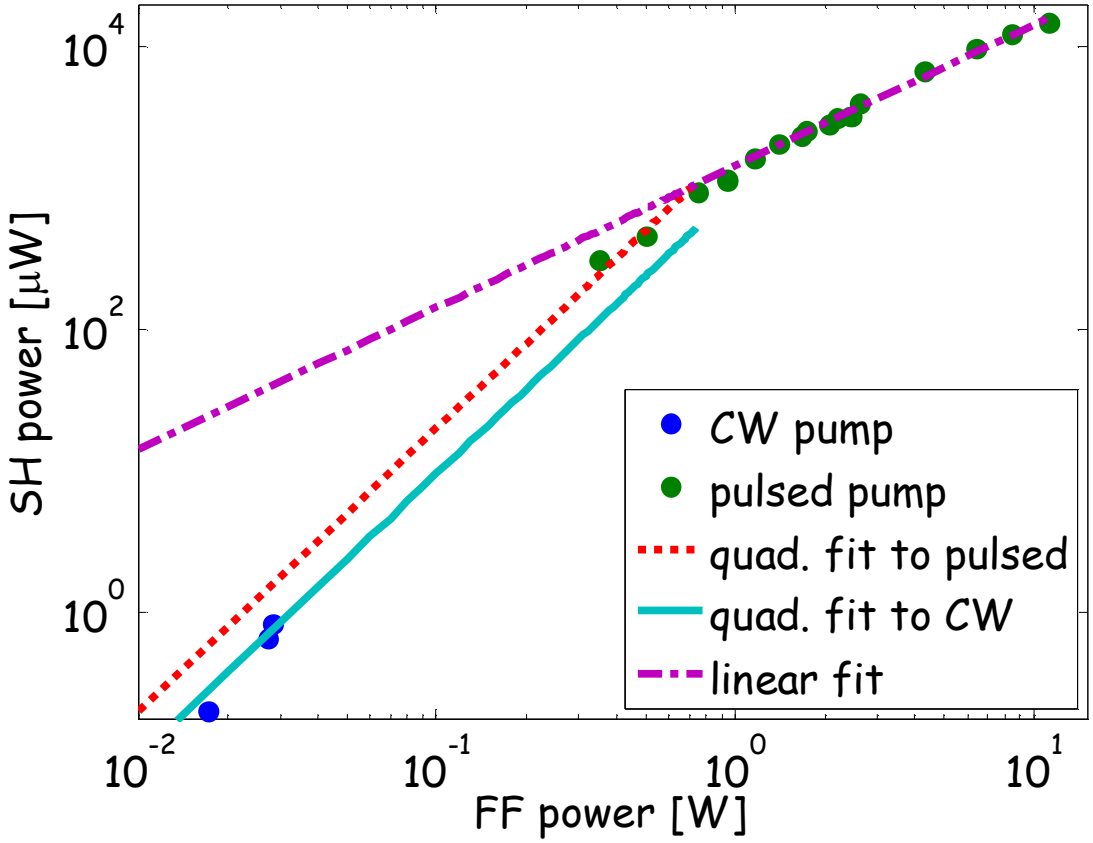
S. Campione et al. *Appl. Phys. Lett.* **104**, 131104 (2014).



Lee et al. *Nature* **511**, 65-69 (2014).

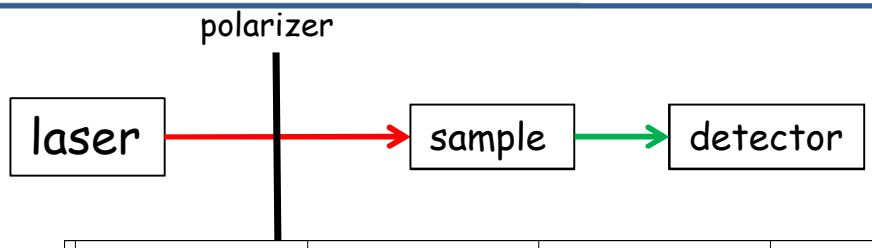
Saturation

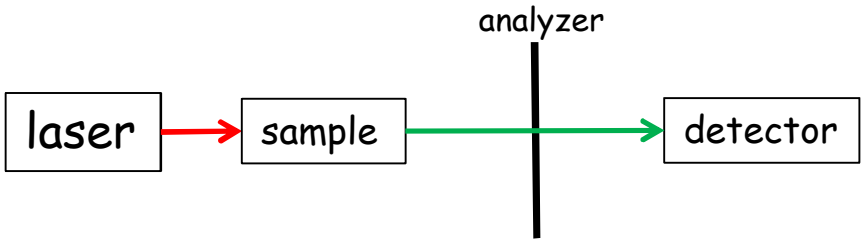
- No CO_2 lasing lines at peak efficiency → High pump intensity using pulsed OPA
- CW data shown at different frequency
- 0.1% conversion in ~700nm path length

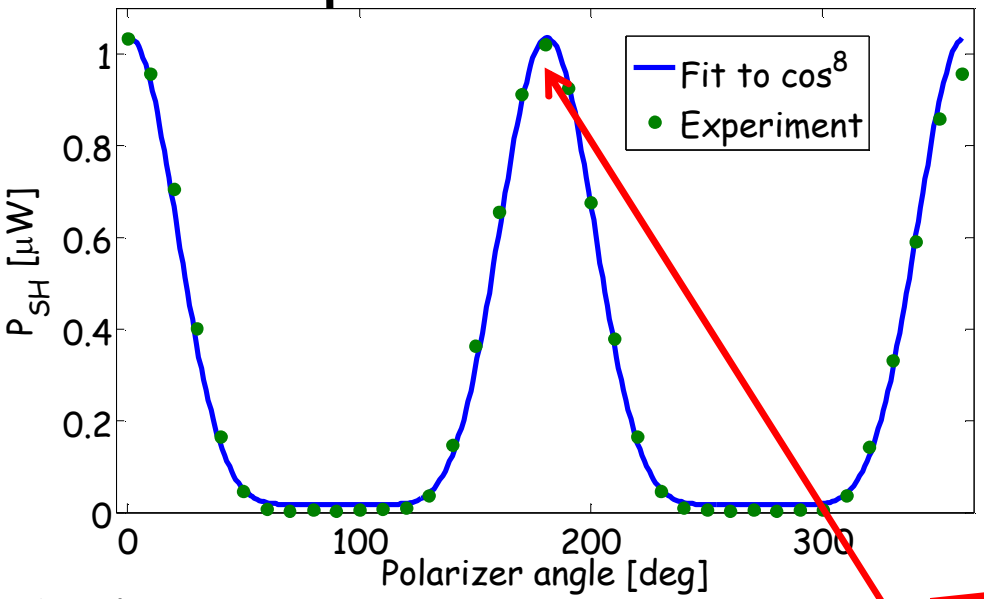


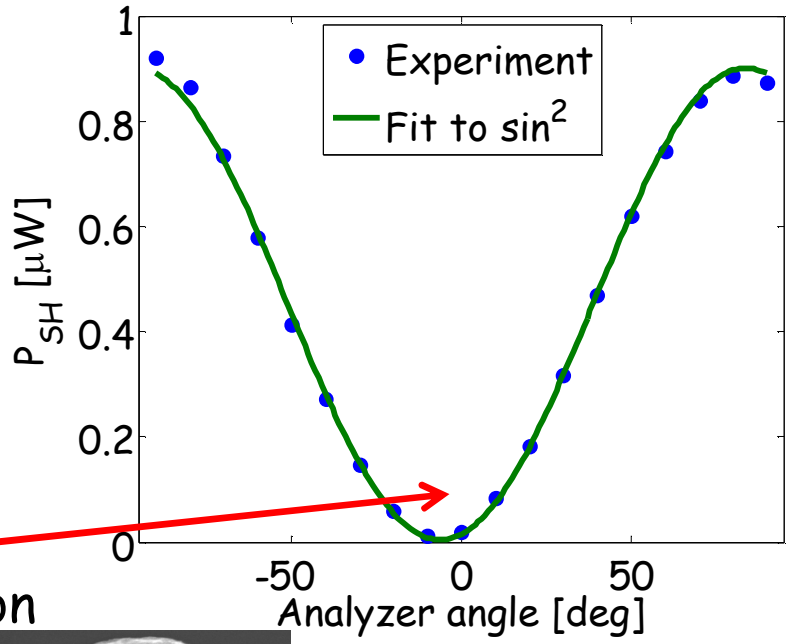
max conversion:
~0.1% @ ~6kW/cm²

Polarization



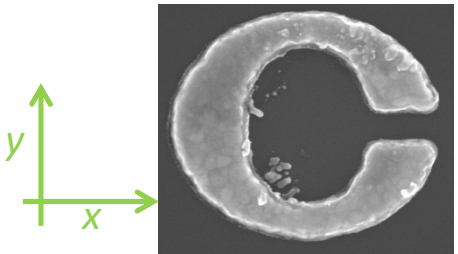






in \ out	X	y
X	--	--
y	☺	--

laser polarization



Summary

- SHG in **ULTRATHIN** device based on quantum-wells coupled with a metallic metasurface.
- **High Efficiency, Saturation Limited**, operation in transmission demonstrated.
- Near perfect **Polarization Separation** between FF pump and SH signal.

S. Campione et al. *Appl. Phys. Lett.* **104**, 131104 (2014).
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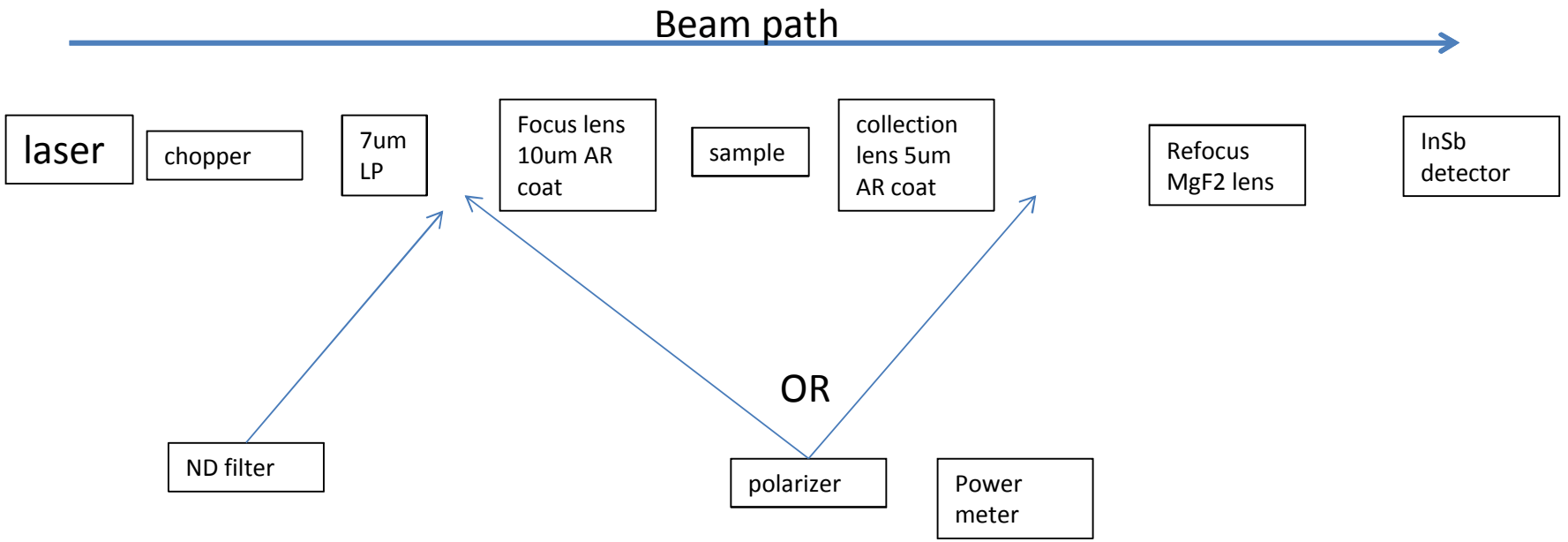
SHG- setup


Beam path
laser
chopper
7um LP
Focus lens 10um AR coat
sample
collection lens 5um AR coat
Refocus MgF2 lens
InSb detector
ND filter
OR
polarizer
Power meter

Polarization backup