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Strong Second Harmonic Generation in Metamaterial-Quantum Well systems

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Introduction

Efficient second harmonic (SH) generation from subwavelength elements is desirable for device miniaturization, phasematching requirement relaxation, etc.

Simple fabrication and easily separating the SH signal from the pump are also highly desirable.

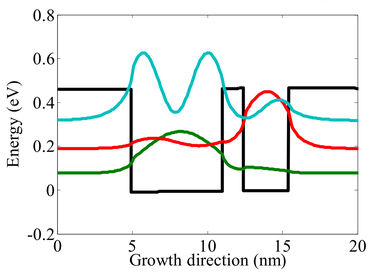
Intersubband transitions in quantum-wells (QWs) have very high $\chi^{(2)}$ but require out-of-plane polarized excitation.

Nanoresonators enable coupling to the QWs and facilitate control over the polarization response.

This experimental work is based on the theory presented in [2].

Double-QW Design

Band structure and energy levels of $In_{.53}Ga_{.47}As/Al_{.48}In_{.52}As$ double quantum

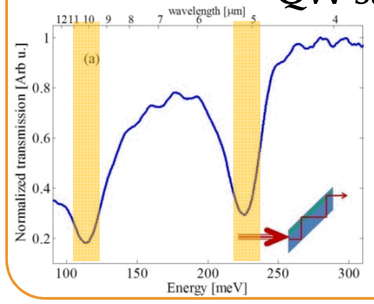


FF:
E2-E1=E3-E2=122meV

SH:
E3-E1 = 244meV

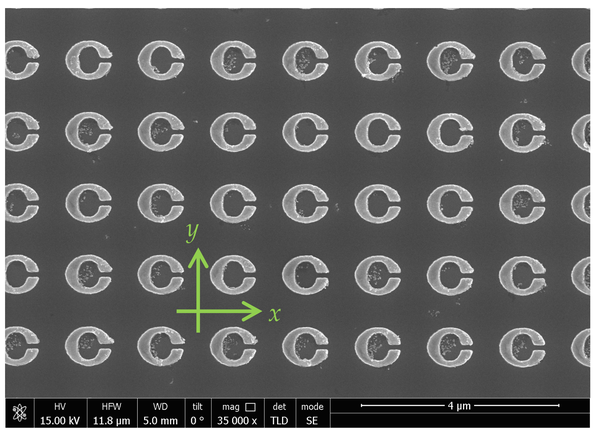
1-2, 2-3 transitions designed with equal energy (122 meV or 10 µm) while maximizing oscillator strengths

Experimental transmission of QW sample



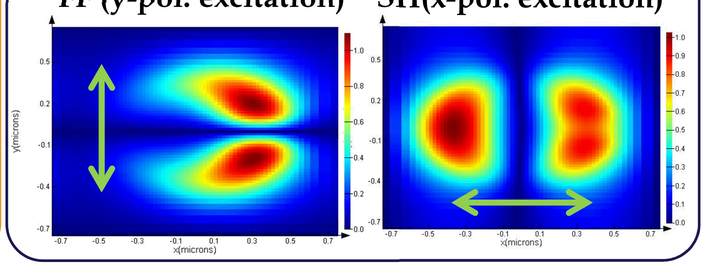
Absorption Dips correspond to 1-2 and 1-3 intersubband-transitions.

Nanoresonator Design

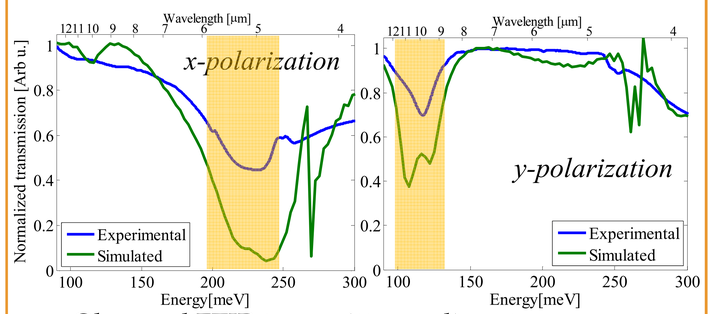


Main resonant modes of the SRR: $|E_z|$ in QW @

FF (y-pol. excitation) **SH(x-pol. excitation)**



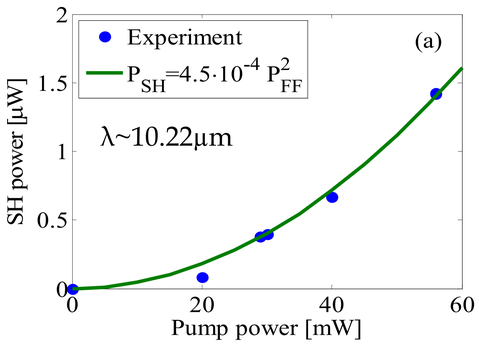
Linear Response



- Observed FTIR transmittance dips at resonances smaller than expected from FDTD simulations due to fabrication imperfections
- Simulations and experiments verify cross-polarization decoupling of fundamental and second harmonic response
- Feature at ~260meV due to array periodicity.
- Slight polarization cross-talk seen only in simulation-not in experiment.
- Splitting in simulations indicates strong coupling[1]

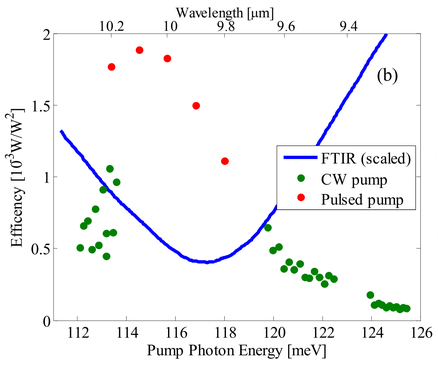
Second Harmonic Generation

Power Dependence



- Pump characteristics: CW CO_2 source, linearly polarized, spot size in sample plane ~100µm diameter
- Quadratic dependence of SH signal on pump power as expected in ref[2]

Wavelength Dependence

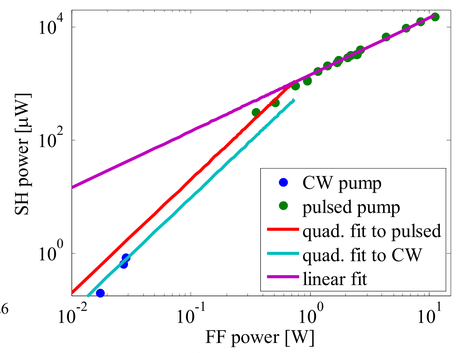


SHG efficiency shows strong frequency dependence as expected from resonant process and presented in ref[2]

Maximum efficiency: ~2 mW/W² Largest achieved in MM-IST systems

Compare to ref[3]

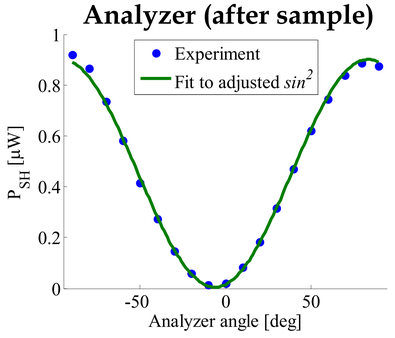
Saturation



- For High intensities, SH signal shows **linear** dependence on pump power .
- **Saturation is reached at ~6kW/cm²**
- Saturation shows ~1.4mW/W slope
- CW data shown for different frequency, for comparison

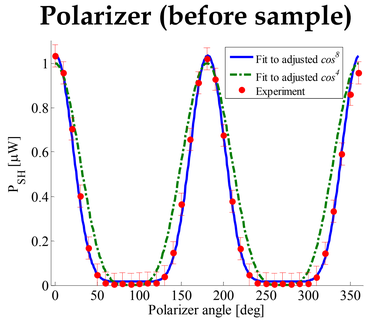
Cross Polarization

Analyzer (after sample)



- Pump polarized parallel to *y-axis* and defined as 0°
- SH signal completely cross polarized with respect to pump

Polarizer (before sample)



- SH generated only for "correctly" polarized input
- Quadratic power dependence also visible in polarization dependence

Polarization separation, saturation and high efficiency not shown in previous work[3]

Conclusion

- Metamaterial-IST device can operate in transmission
- Efficiency two orders of magnitude higher than previously reported[3]
- SH signal is completely decoupled from the pump via polarization orthogonality

References

- [1] A. Benz et al., Nat. Commun. **4**, 2882 (2013)
- [2] S. Campione et al., Appl. Phys. Lett. **104**, 131104 (2014)
- [3] J. Lee et al. Nature **511**, 65-69 (2014)

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