Nonlinear Effects in ITO and GaP Nanolayers

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Introduction

In nonlinear media, the polarization varies with the incoming field differently, with **higher order terms** non-negligible at high field values[1]:

$$P = \epsilon_0 (\chi^{(1)} E + \chi^{(2)} E^2 + \chi^{(3)} E^3 + \dots)$$

Our project focuses on two unusual effects: the **nonlinear Kerr effect (↓)** and **harmonic generation (↓)**.

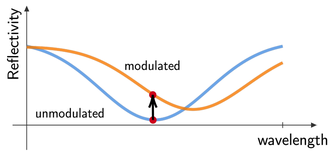


Fig 1: qualitative description of the nonlinear Kerr effect[2]

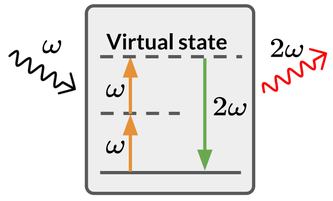
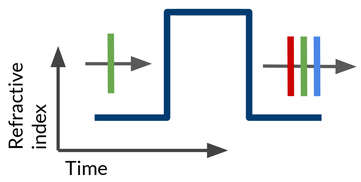


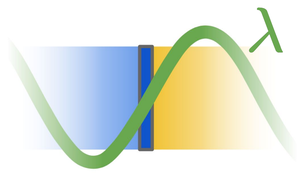
Fig 2: Photon picture of second harmonic generation (SHG) in GaP

The Kerr effect in indium tin oxide (ITO) leads to significant changes to material parameters.

Combining this with a pulsed laser lets us observe time-dependent effects like **time-slit diffraction.**



- **Nanolayers**

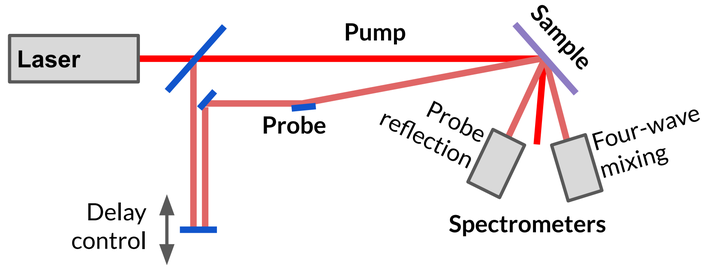


We use **subwavelength layers of material** to get high field enhancement.

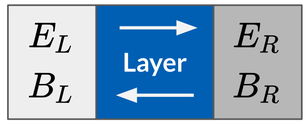
This enables easier **integration into devices**, with applications in optoelectronics, quantum computing, etc.

Method

- **Pump-probe setup lets us test temporal dynamics**



- **Transfer Matrix Method (TMM) for field calculation**



$$\begin{pmatrix} E_L \\ B_L \end{pmatrix} = \underline{\underline{M}} \begin{pmatrix} E_R \\ B_R \end{pmatrix}$$

- **Nonlinear theory[3] to model SHG**

$$\mathbf{E}_{signal} \propto \int_V \mathbf{P}^{\mathbf{NL}} \cdot \mathbf{E_D}$$

Results

- **Linear characterisation**

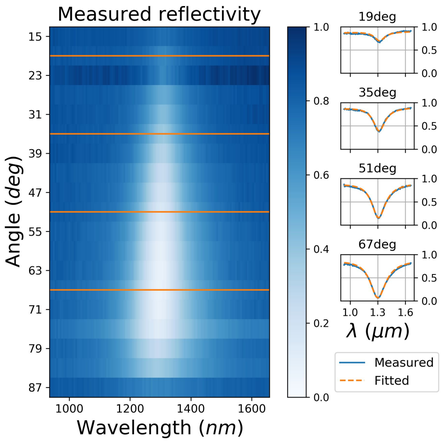


Fig 3: 40 nm ITO on gold sample

Glass 1mm	ITO 40nm	Gold substrate

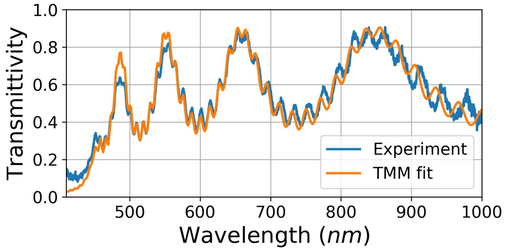


Fig 4: 400 nm GaP sample

GaP 400nm	Glass 10μm	Sapphire 150μm

Fitting of TMM predictions to linear measurements of transmission and reflection not only allows us to fit **material parameters**, but also validate our predictions of **field values**.

Results (contd.)

- **Probe reflectivity modulation measurement**

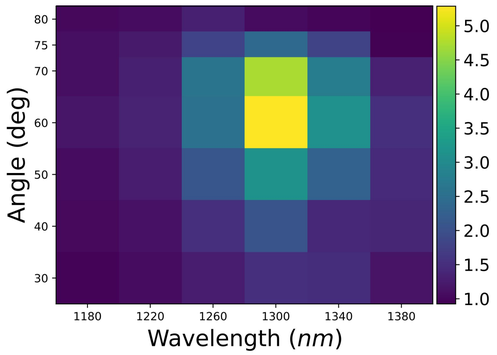
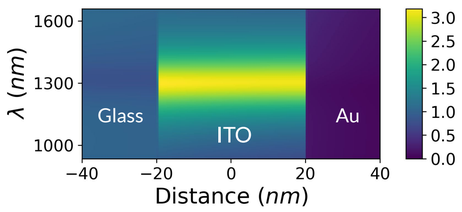


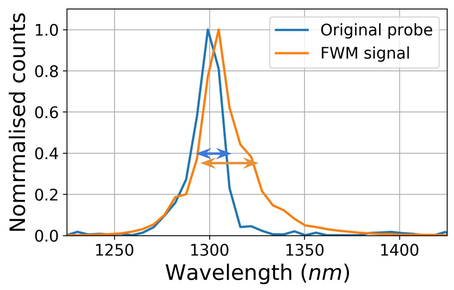
Fig 5: Strong modulation effect due to field confinement in 40 nm ITO

Next steps: white light probe, theoretical modelling of ITO modulation, SHG predictions and measurements for GaP.

- **Fig 6: Field enhancement prediction in ITO (65deg)**



- **Fig 7: Four-wave mixing (FWM) time slit observation**



Conclusions

- We observe very good nonlinear responses from very thin layers, which is a platform for further research.
- Nanolayers have lots of potential as they demonstrate large field enhancement.
- Simulations show that linear properties can be predicted very accurately to fit different material parameters.

Nanolayers are able to generate high **electric field enhancement** and **new frequencies of light**.

References

1. R. W. Boyd, *Nonlinear optics*, 3rd ed. Burlington, Massachusetts: Academic Press, 2008.
2. H. Wang *et al.*, 'Extended Drude Model for Intraband-Transition-Induced Optical Nonlinearity', *Phys. Rev. Applied*, vol. 11, no. 6, p. 064062, Jun. 2019, doi: 10.1103/PhysRevApplied.11.064062.
3. K. O'Brien *et al.*, 'Predicting nonlinear properties of metamaterials from the linear response', *Nature Mater*, vol. 14, no. 4, pp. 379–383, Apr. 2015, doi: 10.1038/nmat4214.