

Studies of the Spin Dynamics of Charge Carriers in Semiconductors and their Interfaces

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Objectives

✦ Measure Important Parameters in Magnetic Semiconductors:

- ◆ **Band-Offset** : Using Internal Photo-Emission (IPE) and SHG Techniques.
- ◆ **Ultrafast Spin Dynamics**: Time-Resolved Photoluminescence and Reflectivity, Faraday Rotation.
- ◆ **Probing Electron-Hole Dynamics**: Time-Dependent Second Harmonic Generation (SHG).

✦ Develop Theoretical Models of Ultrafast Spin Dynamics.

Vanderbilt Capabilities

◆ Series of Ultrafast, High-Power, Tunable Lasers:

FIR and UV OPAs (Optical Parametric Amplifier)

Range: 0.06 – 6 eV

Pulse Energy: 10 μ J

Rep. Rate: 1 KHz

Pulse Width: 150 fs or 3.5 ps

Free Electron Laser

Range: 0.1 – 1 eV

Pulse Energy: ~ 50 mJ

Rep. Rate: 30 Hz

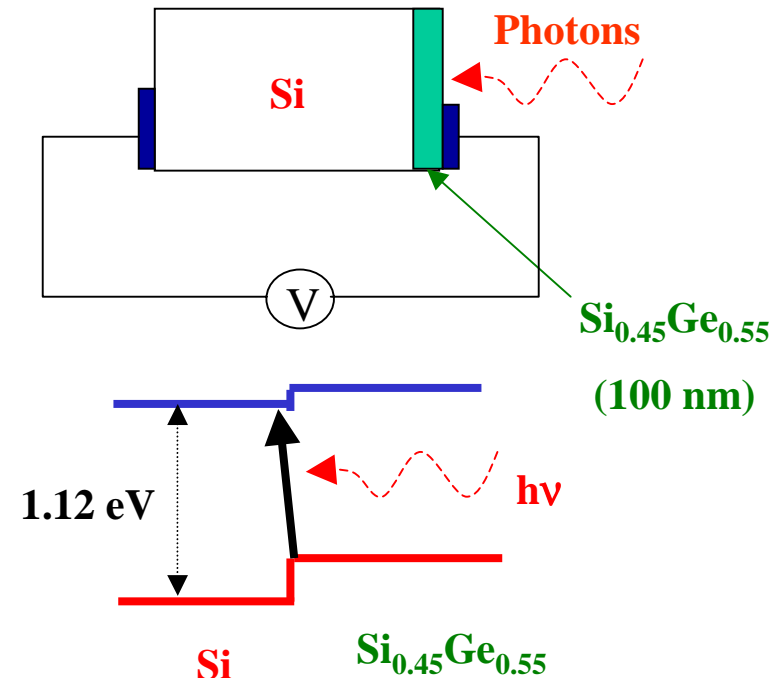
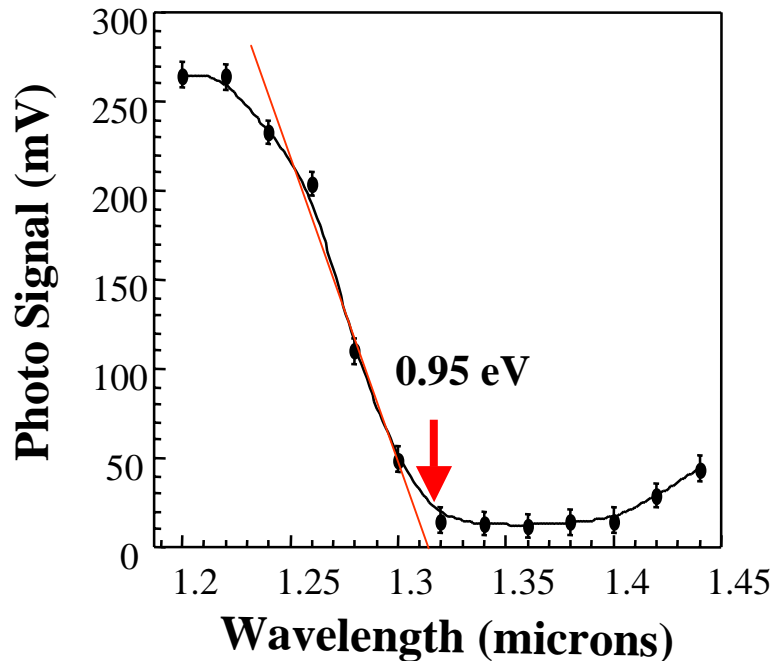
Pulse Width: 4 - 6 μ s

Several Ti:Sapphire and Other Lasers

◆ 9 T Superconducting Magnet Having Four Optical Windows.

◆ Fast Electronics, Optics, etc.

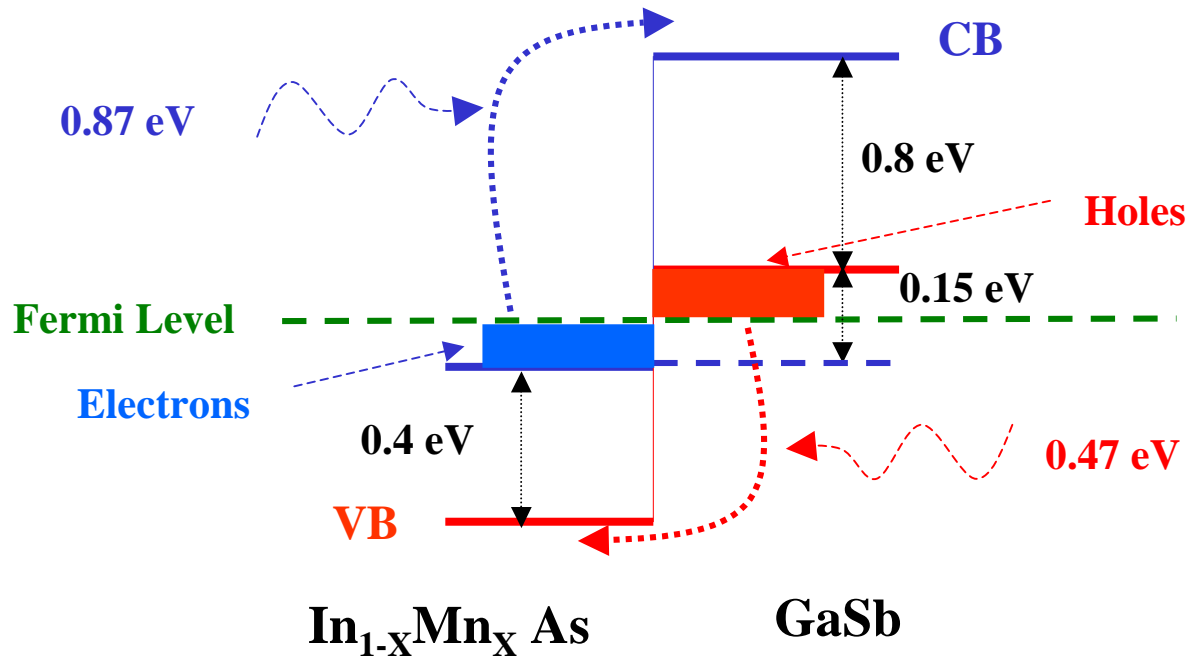
Band-Offset Measurements in Si/Si_{0.45}Ge_{0.55}



- IPE is a sensitive technique to measure band offset (within 10 meV).

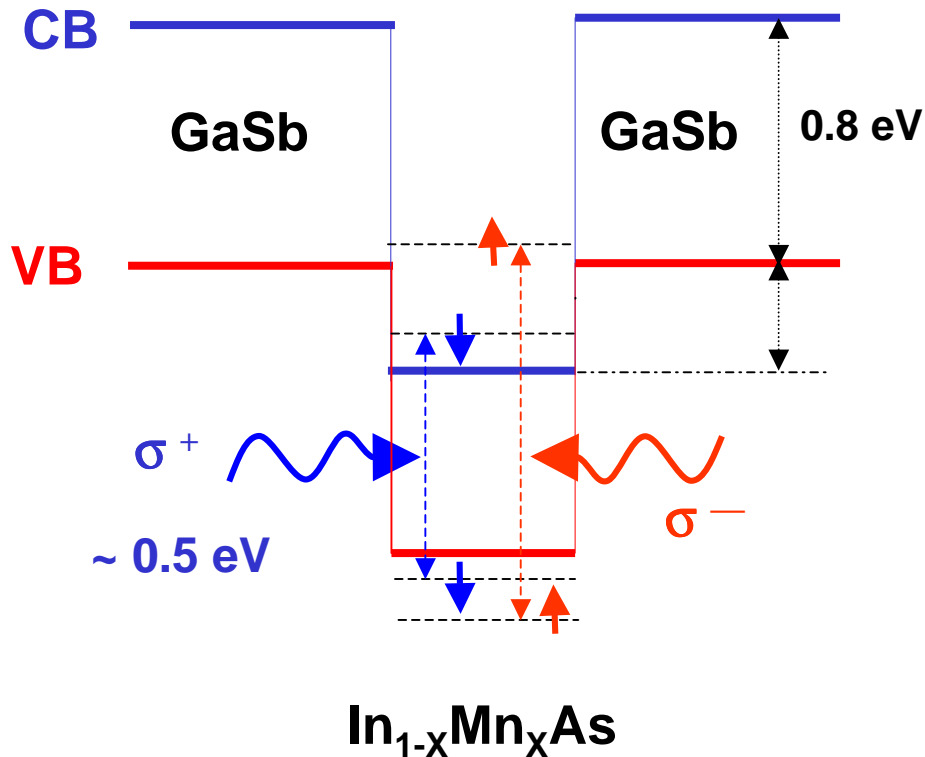
⇒ Can be used to measure band offsets in Magnetic Semiconductors (e.g. InMnAs/GaMnSb)

Proposed Band-Offset Measurements in $\text{III}_{1-x}\text{Mn}_x\text{V}$ / III-V based Semiconductor



- Band offsets can be measured as a function of Magnetic field.

Proposed Lifetime Measurements of Spin-Polarized Carriers in Magnetic Semiconductors (e.g. $\text{In}_{1-x}\text{Mn}_x\text{As}/\text{GaSb}$)



- ◆ Create Photo-Excited Spin-Polarized Carriers in InAs Quantum Well.
- ◆ Probe Spin-Scattering Mechanisms: **Time-Resolved Photoluminescence in Magnetic Field.**
- ◆ Faraday Rotation
- ◆ Study Role of Mn ion in Spin Scattering

Theory: Electric-Field-Induced-SH (EFISH)

General Equation for SHG:

$$\mathbf{P}(2\omega) = \chi_{d,B}^{(2)} \mathbf{E}(\omega)\mathbf{E}(\omega) + \chi_{d,S}^{(2)} \mathbf{E}(\omega)\mathbf{E}(\omega) + \chi_{q,B}^{(2)} \mathbf{E}(\omega)\nabla\mathbf{E}(\omega) + \chi_{d,B}^{(3)} \varepsilon(\omega \sim 0) \mathbf{E}(\omega)\mathbf{E}(\omega)$$

$\chi_{d,B}^{(3)} \varepsilon(\omega \sim 0) \mathbf{E}(\omega)\mathbf{E}(\omega)$: Electric – Field – Induced SH

$\varepsilon(\omega \sim 0)$: Space Charge Field at the Interface

$\mathbf{E}(\omega)$: Electric Field of Fundamental Beam

System With Inversion Symmetry

Under Electric Dipole Approximation

$$\mathbf{P}(2\omega) = \chi^{(2)} \mathbf{E}(\omega)\mathbf{E}(\omega)$$

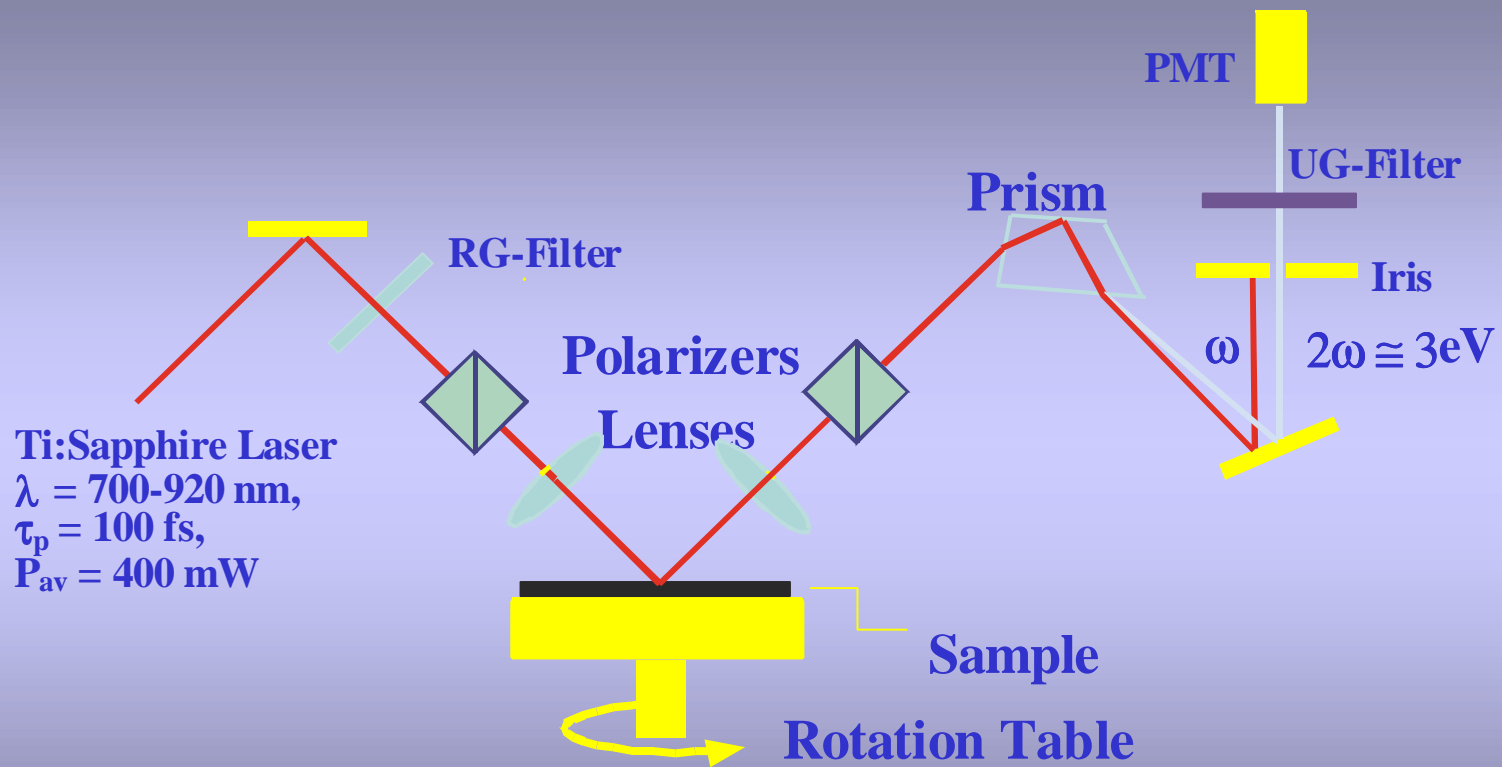
↓ Inversion

$$-\mathbf{P}(2\omega) = \chi^{(2)} (-\mathbf{E}(\omega))(-\mathbf{E}(\omega))$$

$$\chi^{(2)} = 0 \text{ in Bulk}$$

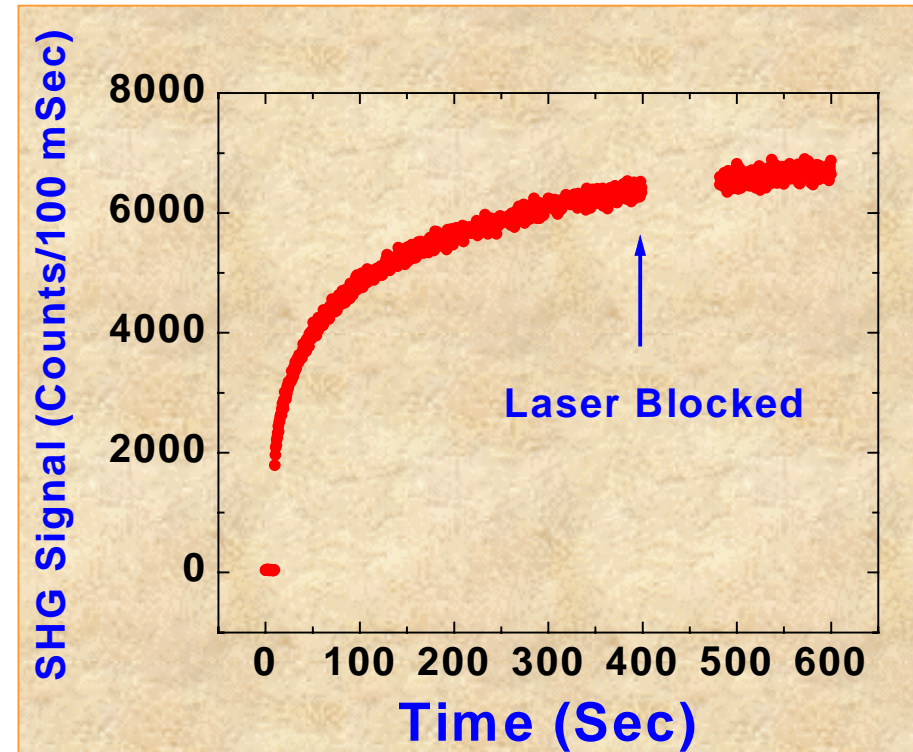
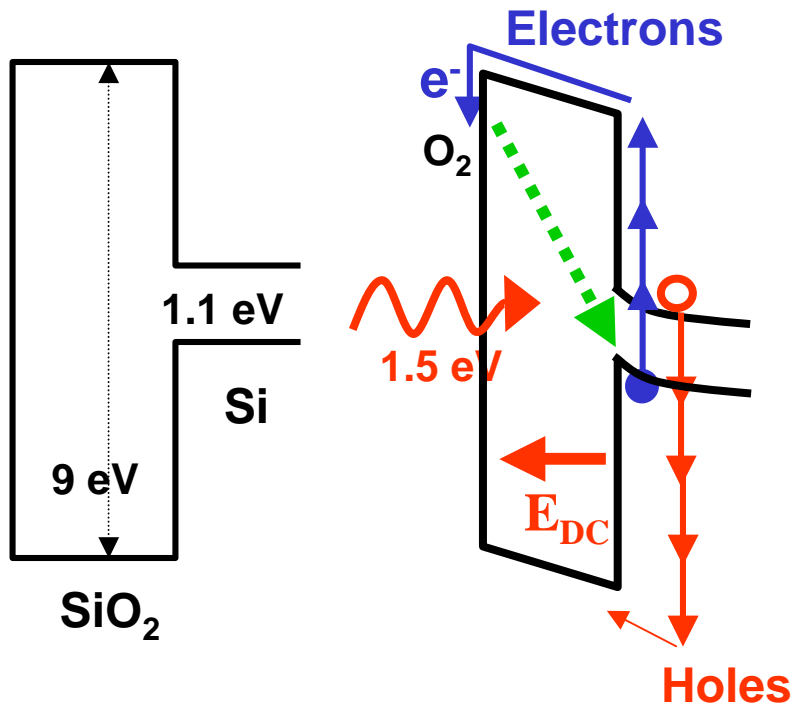
But not at surfaces or with static electric field
where symmetry is broken

Experimental Setup



$$I^{(2\omega)}(t) \propto \left| \chi^{(2)} + \chi^{(3)} E(t) \right|^2 I^{(\omega)2}$$

Electron-Hole Dynamics at Si/SiO₂ Interface

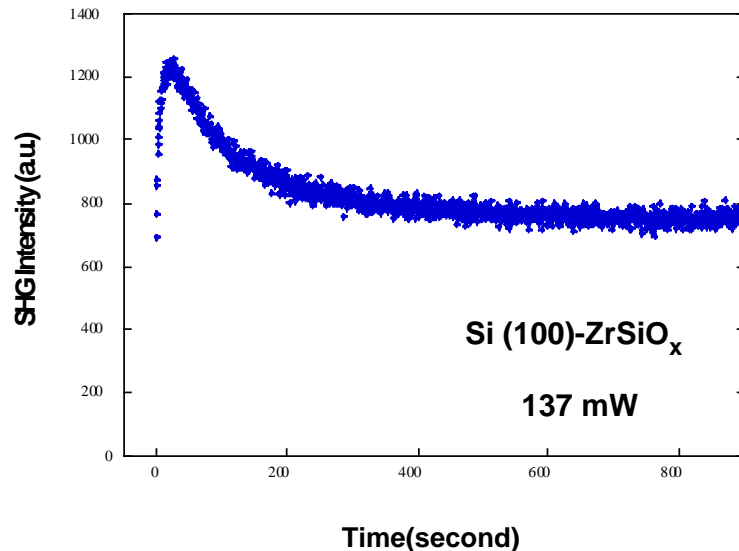
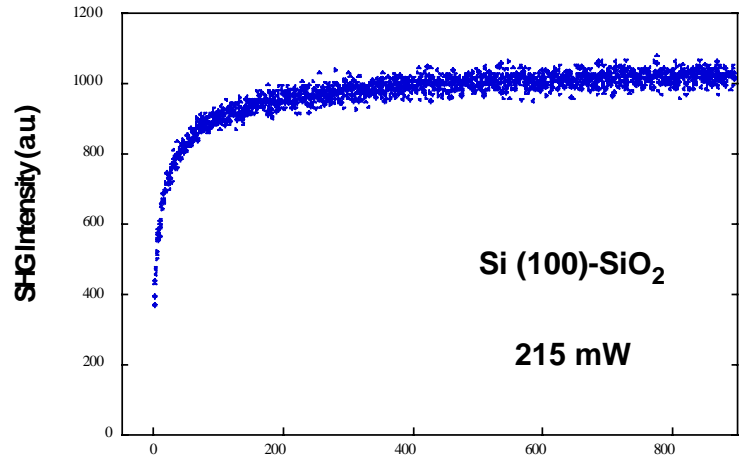


E_{DC} Field ⇒ Charge Separation (Carrier Injection)

- Electrons trapped at Surface
- New Charged Traps in Oxide due to Radiation

Comparison of SiO_2 and ZrSiO_x Oxides

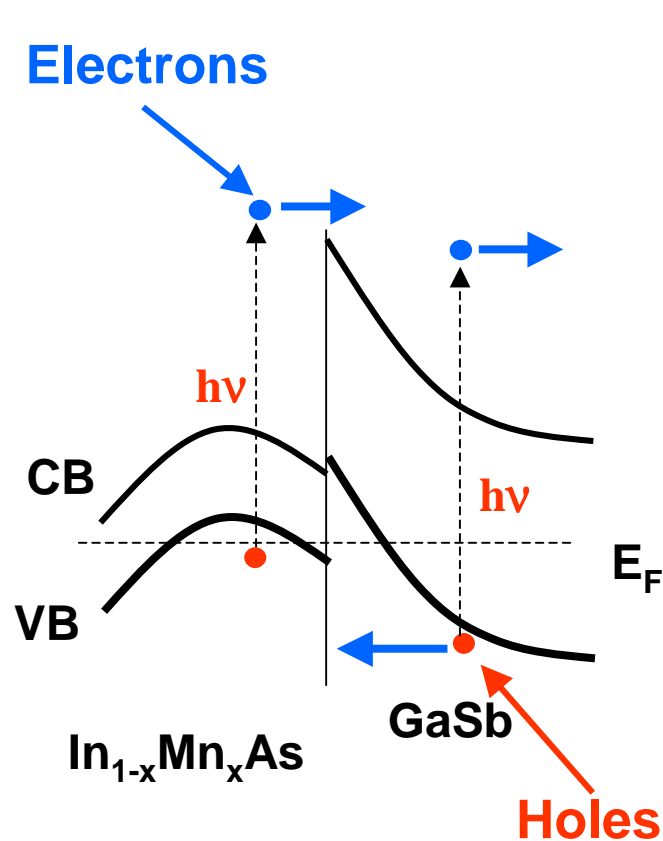
SHG from Si-Dielectrics



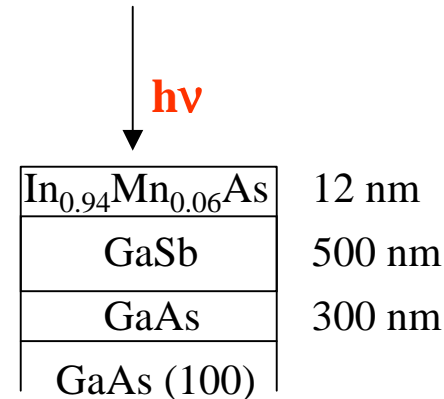
- Qualitative difference in the shape of the curves in SiO_2 and ZrSiO_x :

⇒ Difference in electron and hole injection rate?

SHG measurements to probe electron-hole Dynamics in Magnetic Semiconductor



Koshihara *et al.*, PRL 78, 4617 (1997)



◆ SHG measurements can probe dynamic electric field due to electron-hole migration, induced by photons.

⇒ Understand photo-induced Ferromagnetism.

Summary

- **Band-Offset** : Internal Photo-Emission (IPE) and SHG Techniques.
- **Lifetime of Photo-Excited Spin-Polarized Carriers**: Faraday Rotation, Time-Resolved Photoluminescence and Reflectivity.
- **Probing Electron-Hole Dynamics**: Time-Dependent Second Harmonic Generation (SHG).
- **Develop Theoretical Models** of Ultrafast Spin Dynamics.

Samples

- InAs/GaMnSb, InMnAs/GaMnSb : **BO**
- InAs/GaSb : **BO, SHG**
- InMnAs/GaSb : **SHG**
- GaSb/InMnAs/GaSb QW : **LT**

BO: Band Offset

LT: Life Time

SHG: Second Harmonic Generation