X-ray induced optical transparency
&
x-ray/optical photon interactions in GaAs

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Think about the x-ray pulse as a pump, not a probe.

Also, instead of just x-ray pump/laser probe, think of both the x-ray and the laser as pump beams.
What happens when an x-ray is absorbed in a semiconductor:

1. Photoelectron is ejected, having significant kinetic energy.
   • This energy is lost by inelastic scattering from outer electrons
   • Causes electron hole pairs with excess energy
   • These photocarriers lose energy (phonons etc) and settle into the bottom of conduction band (<ps)
   • Electron-hole recombination (fluorescence), with ~200 ps lifetime in GaAs

2. The hole in the K shell is filled by an L-shell electron, followed by emission of Auger electron.
   • This has even more kinetic energy, and does all the things outlined above.

3. The hole in the L-shell is filled….
These processes lead to lots of electrons in the conduction band, where electron-hole recombination is the bottleneck.
Experiment: X-ray pump, laser probe of a thin GaAs wafer; measure transmission of laser pulses for photon energies near the band gap.

X-ray pulses: ~80 ps duration, 12 keV, 21 μJ/pulse, 20 Hz (APS)

Laser pulses: ~2 ps duration, ~860 nm, variable power density.

Three Results:

1. X-ray induced optical transparency.


3. Laser hole-burning extinguished by x-rays!
X-ray induced optical transparency in GaAs, seen for photon energies just above the band gap.

1. X-ray induced optical transparency.

Mystery: some x-ray induced opacity is seen for photon energies below the gap. Transient localized states?

Increasing the laser power makes the x-ray induced transparency last longer!

Recombination time is only \(~200\) ps in GaAs.

1. X-ray induced Pauli blocking reduces the thickness of the absorbing part of the crystal, for photons just above the band gap, in a time-dependent manner.

2. Optical hole burning from high intensity pulses also changes the effective thickness of the absorbing crystal, in a time dependent manner.

\[\text{~60 \, \mu m \, GaAs \, wafer}\]
3. Laser hole-burning extinguished by x-rays!

At higher laser power levels, the transmitted intensity dips when the x-ray pulse just arrives…

Similar (unexplained) results seen in VUV XFEL reflectivity data by others….
3. Laser hole-burning extinguished by x-rays!

A. The (high power) laser pulse by itself induces transmission by Pauli blocking: hole burning.

B. Energetic photoelectrons and Auger electrons created by x-ray absorption scatter the laser-excited electrons out of the conduction band, reducing Pauli blocking and increasing absorption.

C. Highly energetic conduction band electrons thermalize to bottom of band, increasing transmission.
Observations:

1. A single x-ray pulse puts a lot of electrons in the conduction band of GaAs.

2. A single optical laser pulse also puts a lot of electrons in the conduction band of GaAs.

3. The optical pulse interacts with the x-ray-induced charges.

4. The x-ray pulse interacts with the laser-induced charges.

Excited carriers mediate the interaction between x-ray and optical (band gap) photons.
Need to do measurements “inside” the x-ray pulse.
Optoelectronic detection of synchrotron x-ray pulses:
Partial success, but big loss of current. May need Sector 14 to explore this....
Science can be done “inside” a synchrotron pulse!

Thanks! Questions?