Effects of Compositional Disorder on Ultrafast Photocarrier Dynamics in a-$Si_{1-x}Ge_x$:H

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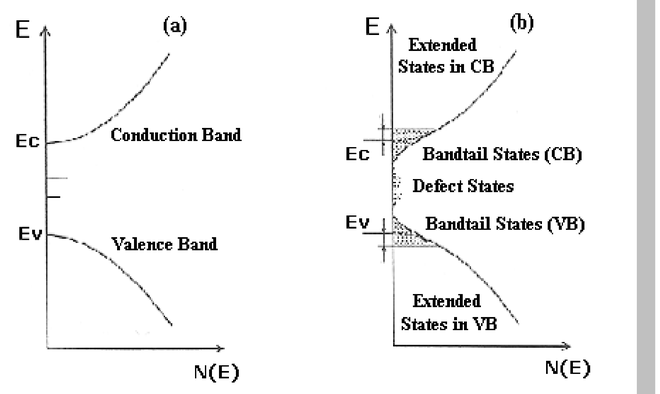
ABSTRACT

Amorphous semiconductors have been of substantial physical interest for many years due to their potential for solar energy generation as well as their status as a prototypical material for investigating the effects of disorder on electronic properties in semiconductors. Silicon-germanium alloys (a-$Si_{1-x}Ge_x$:H) are of particular interest due to their tunable band gap and ability to be compositionally tailored to contain varying degrees of disorder. Systematically altering the Ge content allows for an investigation of the effects of compositional disorder on electronic properties. Time-resolved optical absorption measurements were carried out on a-$Si_{1-x}Ge_x$:H using optical pulses 35 fs in duration centered at 800 nm generated by an amplified Ti:S laser system. Photoinduced carrier absorptions were measured at various pump fluences and correlated to photocarrier densities. The time-resolved responses in these a-$Si_{1-x}Ge_x$:H materials are consistent with diffusion-limited bimolecular recombination, with decreased mobility in more disordered materials.

INTRODUCTION

The loss of long-range crystalline order in a semiconductor lattice profoundly affects the nature and dynamics of the generated photocarriers. In amorphous semiconductors, the random potential fluctuations associated with the disorder result in the localization of low-energy carriers, substantially reducing the effective carrier mobility. Multiple trapping of carriers into localized states (the Urbach Tail) with a distribution of binding energies, as well as hopping transport between localized sites at a distribution of distances, can result in dispersive transport, in which photogenerated carriers exhibit a time-dependent mobility. Alloys with increasing Ge content possess a higher degree of disorder.

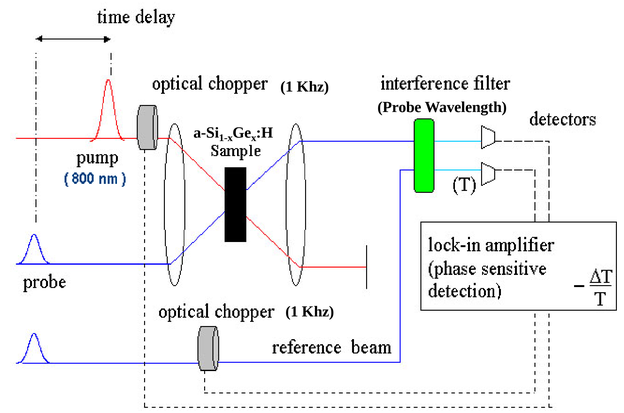
Density of States (DOS) as a function of energy
(a) Crystalline Semiconductors
(b) Amorphous Semiconductors



EXPERIMENT

Time-resolved differential transmittance measurements were carried out using the pump-probe technique. Optical pulses 35 fs in duration were generated by a Ti:sapphire laser system operating at a repetition rate of 1 kHz. Pump pulses centered at 800 nm were used to excite the a-$Si_{1-x}Ge_x$:H, and probe pulses generated from a white light continuum detected the decay dynamics of the initially excited carriers. A reference beam with a lockin amplifier was used for noise reduction and normalization.

Setup for the Pump-Probe Experiment



RESULTS

Data can be accurately fit to a simple bimolecular recombination model:

$$\frac{dn}{dt} = -kn^2 \qquad (1)$$

Where k is proportional to a time-dependent mobility defined by

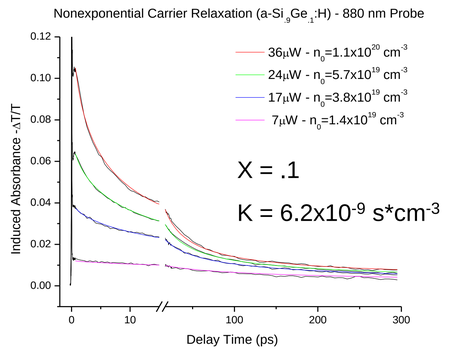
$$\mu(t) = \mu_0 (\nu_0 t)^{\alpha - 1} \qquad (2)$$

Yielding:

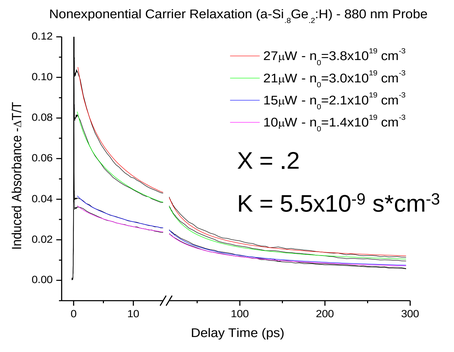
$$n(t) = \frac{n_0}{1 + n_0 k_0 (\nu_0 t)^{\alpha}} + c n_0 \qquad (3)$$

The measured photoinduced absorbance is directly proportional to the carrier population, with a small offset due to lattice heating.

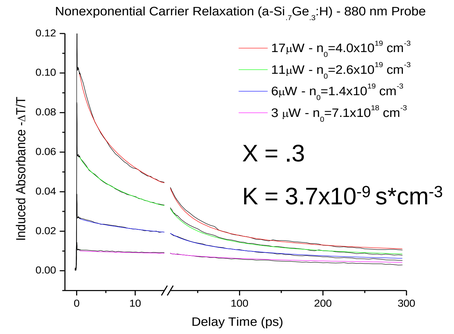
a)



b)



c)



Time-resolved induced absorbance response for a-$Si_{.1-x}Ge_{.x}$:H probed at various initial excitation densities. Solid black lines represent the original data and colored solid lines represent fits to model given by Eqn. (3). (Note Scale Break at 15 ps)

CONCLUSIONS

Preliminary results give bimolecular recombination constants that decrease systematically with higher Ge content, reflecting decreasing mobility with increasing disorder. Future work will correlate these results with time-resolved THz measurements on these materials.

ACKNOWLEDGMENTS

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