CONSRT

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DARPA University Photonic Research Program

Center for Optoelectronic Nanostructured SemiconductoR Technologies

Professor Connie Chang-Hasnain, Director CONSRT- 0806-31

Tunable Optical Delay with Carrier Induced Exciton Dephasing in Semiconductor Quantum Wells

Recent dramatic experimental demonstration of slow and fast light has stimulated considerable interest in the dynamic control of the group velocity of light and in the development of tunable all-optical delays for applications such as optical buffers. Earlier slow light studies have used physical mechanisms such as electromagnetically induced transparency (EIT), coherent population oscillation (CPO), stimulated Brillouin and stimulated Raman scattering, and optical wavelength conversion. Materials used in these studies range from atomic vapors, doped ions in crystals, optical fibers, and semiconductors. All these schemes are based on the use of coherent nonlinear optical processes.

CONSRT researchers led by Professor Wang at the University of Oregon have demonstrated experimentally a scheme that uses incoherent nonlinear optical processes to realize tunable optical delays in semiconductors. The new scheme exploits the strong Coulomb interactions between excitons and free carriers and uses optical injection of free carriers to broaden and bleach an exciton absorption resonance.

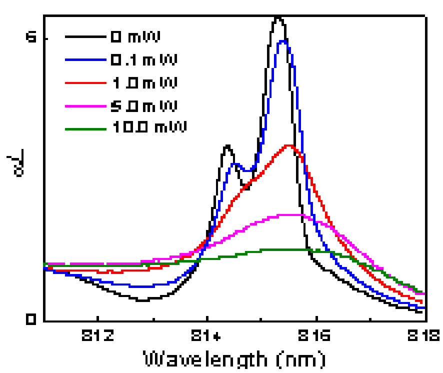

Fig.1, Effects of free carrier injection on absorption spectra at T=80 K. Free carriers are injected by a pump beam at λ =795 nm with power indicated in the figure.

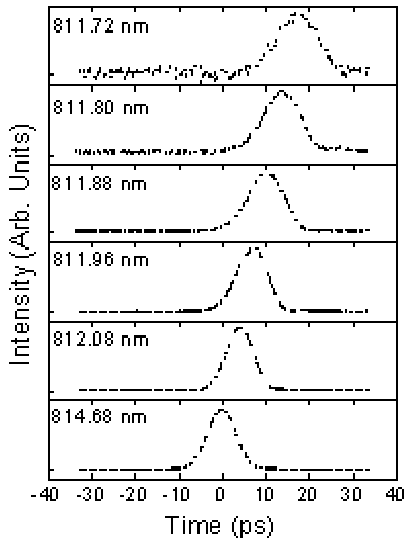

Fig 2 Time-of-flight measurements of a signal pulse after transmission through the QW sample. Central wavelength of the signal pulse is indicated in each figure. The measurements were carried out at T=20 K and without free carrier injection.

A fractional delay exceeding 200% has been obtained for an 8 ps optical pulse propagating near the heavy-hole (HH) excitonic transition in a GaAs quantum well (QW) structure.

Figure 1 shows absorption spectra of a GaAs QW near the band edge with and without optical injection of free carriers. The sample used in this study contains 50 periods of 17.5 nm GaAs wells and 15 nm $Al_{0.3}Ga_{0.7}As$ barriers. For optical injection of free carriers, the wavelength of the pump beam is set to slightly above the band gap of the GaAs QW. A pump beam with an average power of 1 mW (using a pump spot size of order 200 μm) generates approximately a carrier density of $3x10^9/cm^2$. At T=80 K, the exciton resonance nearly vanishes at a pump power near 10 mW. For the pulse delay measurement, a signal pulse with a duration of 8 ps and a spectral bandwidth of 0.2 nm is used. The pulse delay is measured with sum frequency generation in a BBO crystal.

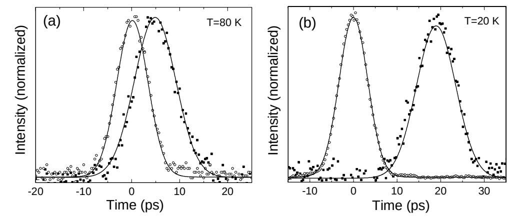

Fig.3. Time-of-flight measurements of a signal pulse after transmission through the QW sample with (open circles) and without (squares) free carrier injection by a pump beam at λ=795 nm. (a) T=80 K and I=2 mW. (b) T=20 K and I=4 mW. Solid lines are numerical fit to a Gaussian. The central wavelength of the signal pulse is at λ=815.69 nm and λ=811.72 nm for (a) and (b), respectively.

Figure 2 shows the time-of-flight measurement of a weak signal pulse after its transmission through the QW sample (no free carrier injection was used in these measurements). The signal pulse becomes more delayed as the central wavelength of the pulse approaches the heavy-hole exciton resonance. The spectral broadening and optical bleaching of the exciton absorption resonance shown in Fig. 1 then provides an effective mechanism for realizing tunable optical delay.

Figure 3 compares directly time-of-flight measurements of the signal pulse after its transmission through the QW sample with and without the optical injection of free carriers by a pump beam. For clarity of display, normalized intensity is shown in Fig. 3. Fractional pulse delay (the ratio of the pulse delay over the pulse duration) exceeding 200% has been observed at T=20 K. Smaller fractional delays have been observed at higher temperatures. The large delay, however, is also accompanied by a broadening or reshaping of the temporal line shape of the signal pulse, as expected theoretically.

These studies should stimulate further activities to exploit unique optical properties of semiconductors for tunable optical delays.

--Hailin Wang (hailin@uoregon.edu)--