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13. ABSTRACT (Maximum 200 words)

A systematic investigation of ultrafast electron tunneling processes in semiconductor microstructures in presence of inter-valley (X-Γ) scattering, infrared radiation, phonons, and Coulomb interaction has been undertaken. Various important time constants involved in high speed electronic and photonic device operation were obtained such as the lifetime of a quasi-bound state, the time needed for an electron to tunnel into a well through a barrier, and the escape time for an electron to tunnel out from a well through a barrier. Our investigation under the period supported by the grant has resulted in ten journal publications.

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ULTRAFAST PROCESSES IN TUNNELING MICROSTRUCTURE DEVICES

Grant Number: DAAL03-89-0110

Final Report, June 18, 1993

Dr. R. R. Alfano and Dr. Kai Shum

1. Statement of The Problem Studied

Under the period supported by the grant the following problems are studied during the time period supported by the grant: (1) electron tunneling in presence of inter-valley (X-Γ) scattering; (2) photon-assisted tunneling; (3) infrared photon emission in tunneling microstructure; (4) Excitonic effect on photoexcited electron wave-packet oscillation in double quantum well structures; (5) three-dimensionally confined excitons in semiconductor quantum dots; (6) electron tunneling dynamics in the presence of plane wave phonons; and (7) charging dynamics in the well of a double barrier tunneling structure in the of localized phonon modes.

2. Summary of The Most Important Results

By solving the time-dependent Schordinger equation in one dimension, we have investigated intervalley scattering across the real interface of double barrier structure between Γ (in GaAs) and X (in AlAs) electrons. We found that Γ-like and X-like electrons oscillate inside the structure with an oscillation frequency inversely proportional to the energy separation between the first subband minima originated from the Γ and X band edges. At the anticrossing point of X-Γ mixing, the Γ-like electrons of the structure will be strongly confined within the well of the structure and will not able to escape even though the barrier are as thin as less than 30 A.

We have investigated the electron tunneling current through a double barrier structure under infrared radiation using a Green's function approach. Photon-assistant tunneling current was found to substantially enhanced by several orders of magnitude when it is

compared with the dark state. More importantly, the photon-induced resonance tunneling process can be switched and controlled by changing the applied static voltage.

We have theoretically obtained the spontaneous infrared photon-emission spectrum of an electron tunneling through a semiconductor double-barrier structure. The peak photon emission power of 10^{-7} W per well can be achieved for an injected current of 50 mA. Our results are consistent with the measured value of 10^{-9} W per well be Helm *et al.* [Phys. Rev. Lett. 63, 74 (1989)] when nonradiative processes and other factors are taken into account.

We have numerically demonstrated in both the time and energy domains that Coulomb interaction between electron and hole (excitonic effect) affects the oscillation behavior of a photoexcited electron wave packet in coupled double quantum wells. This effect is finite and appreciable (about 13%) and can not be neglected.

We have experimentally studied exciton formation, relaxation, and recombination processes in CdSSe quantum dots. We have observed 1S to 1P excitonic transition in CdSSe quantum dots for the first time as a distinct peak in a subpicosecond visible laser pulse (585 nm) induced infrared absorption spectrum (2 - 5 μm). Temporal behavior of the induced absorption at the peak indicates that the 1P to 1S exciton relaxation is faster than 0.7 ps and 1S exciton lifetime is about 20 ps at room temperature.

We have investigated the influence of anisotropic effective mass on electron and hole eigen energies in semiconductor quantum dots by solving Schordinger equation in spheroidal coordinates. We found that for dot materials in which longitudinal electron or hole effective mass is quite different than their transverse effective mass there are significant deviations in the energy levels from those obtained by commonly used average effective mass approximation.

We have found that any time constant related to the electron tunneling processes in double barrier structure such as charge built-up time, transit time, escape time are hardly affected by the presence of phonons in any modes. However, the magnitude of tunneling

current and the charge inside the quantum well of the double barrier structure are reduced in comparison with that in case of elastic tunneling in the presence of the symmetric and confined phonons of the structure. This reduction is negligible for the case of interface antisymmetric phonon mode. We have obtained temperature dependent of resonant current density and compared with the experimental data reported by Bar-Joseph *et al.* [Phys. Rev. B 44, 8361, 1991]. From this comparison, it is clear that inelastic scatterings such as phonon scattering will affect elastic tunneling process to a maximum extent of 10%.

3. List of Publications

(1) "Photon-Assisted Resonant Tunneling Through a Double-Barrier Structure for Infrared-Radiation Detection", W. Cai, T. F. Zheng, P. Ho, M. Lax, Kai Shum, and R. R. Alfano, Phys. Rev. Lett. 65, 104 (1990)

(2) "Spontaneous photon emission spectrum of tunneling electrons in a double barrier structure", Guang Bai Kai Shum, and R. R. Alfano, J. Appl. Phys. 70, 1025 (1991).

(3) "Density of States in Semiconductor Nanostructures", Kai Shum, J. Appl. Phys., 69, 6484 (1991).

(4) "Resonant level lifetime in GaAs/AlGaAs double-barrier structures in the consideration of Γ-X mixing", T. F. Zheng, M. Lax, Kai Shum, and R. R. Alfano J. Appl. Phys. 69, 8387 (1991).

(5) "Picosecond Γ-X carrier scattering in GaAs/AlAs superlattice", Y. Takiguchi, Kai Shum, R. R. Alfano, and M. Dutta, SPIE Vol.1599, 90 (1991).

(6) "Investigation of the L6-X6 intervalley scattering in AlGaAs by measuring hot carrier dynamics in X satellite valley" W. B. Wang, Kai Shum, R. R. Alfano, D. Szmyd, and A. J. Nozik, Semicond. Sci. Technol. 7, 173 (1992).

(7) "Excitonic effect on coherent oscillation of a photoexcited wave packet in double quantum wells", J. M. Mohaidat, Kai Shum, and R. R. Alfano, Phys. Rev. B 45,

3822 (1992).

(8) "L6-X6 intervalley scattering time and deformation potential for Al(0.6)Ga(0.4)As determined by femtosecond time-resolved infrared absorption spectroscopy", W. B. Wang, Kai Shum, R. R. Alfano, D. Szmyd, and A. J. Nozik, Phys. Rev. Lett. 68, 662 (1992).

(9) "Observation of the 1P excitonic state in Cd(S,Se)-glass quantum dots", Kai Shum, W. B. Wang, R. R. Alfano, and K. M. Jones, Phys. Rev. Lett. 68, 3904 (1992).

(10) "A field-effect GaAs laser diode with controlled carrier distribution in central and satellite valleys", K. Sutkus, Kai Shum, and R. R. Alfano, Photonics Technol. Lett. Vol.9, 982 (1992).

The following manuscripts are in review process at various journals.

(1) "Electron tunneling dynamics through a double barrier structure in presence of phonons", J. M. Mohaidat, Kai Shum, and R. R. Alfano, submitted to Phys. Rev. B, 1993.

(2) "Ultrafast charging dynamics in a double barrier structure in the presence of localized phonon modes", J. M. Mohaidat,Kai Shum, and R. R. Alfano, submitted to Appl. Phys. Lett., 1993.

4. List of All Participating Scientific Personnel

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