Fundamental limits to the Urbach tail in GaAs quantum wells

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Contrary to the predictions of band theory, it has long been experimentally observed that, the band edges of insulators are blurred with an exponential density of states that extends into the bandgap [1]. Interestingly the functional form of the spectral and the temperature dependence of these bandtail states is almost universal (Urbach rule) across insulators, irrespective of the magnitude of the bandgap or the strength and nature of disorder [1, 2]. Despite three decades of extensive work on quantum wells (QWs), this is the first comprehensive study of the bandtail states in a quasi-two-dimensional system, done not only with the aim of establishing the Urbach rule for GaAs QWs [Fig. (a)], but also to elucidate the origin of these tails at low temperature. A fundamental understanding of these bandtail states is relevant, e.g., in understanding the feasibility of laser cooling of semiconductors by anti-Stokes PL, and the limitations in treating the semiconductor ground state at par with the QED vacuum in context of phenomena like virtual photoconductivity.

Through low temperature electro-absorption (photoconductivity) measurements we have systematically verified the assumptions of a rigorous version [2] of the classic Dow-Redfield theory [1] that is also valid at low temperatures. We have found that broadening of the excitonic resonance due to the electric field of phonons is the fundamental mechanism for bandtailing in high quality QWs. At low temperatures (4K), this is essentially due to the zero-point phonon modes and gives a fundamental limitation to the Urbach energy, $E_u \sim 2$ meV. Furthermore, from the magnetic field dependence of the excitonic linewidths, we have inferred that the interface disorder of large correlation length found in samples of poor quality also strongly affects the bandtails [3].

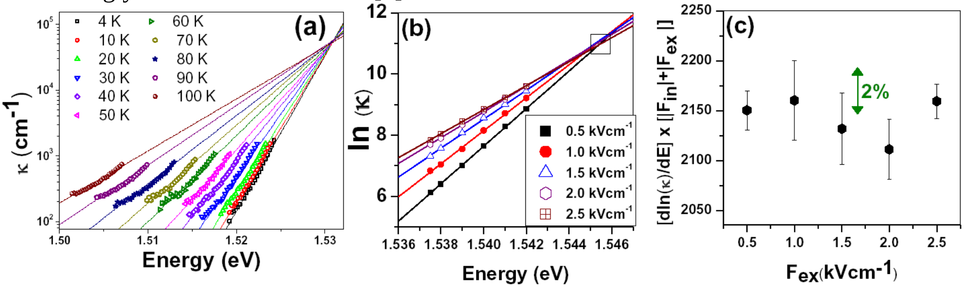

Figure: (a) Urbach rule in a high quality GaAs QW. (b) The exponential slope of the absorption coefficient κ below the energy gap is modified on application of in-plane electric field F_{ex}, in accordance with the Dow-Redfield theory. (c) $\kappa \sim \exp[C\,(E-E_0)/(|F_{in}|+|F_{ex}|)]$ predicts that product of the logarithmic derivative of the absorption coefficient times the total ($|F_{in}|+|F_{ex}|$) electric field should be constant. The electric field F_{in} due to the zero-point phonons is inferred to be 3kVcm^{-1}.

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