Interplay of Collective Excitations in Quantum Well Intersubband Transitions

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Interaction of a laser field and a semiconductor quantum well (QW) with multiple subbands displays some of the most fascinating many-body effects involving various collective excitations such as the Fermi-Edge singularity (FES) and intersubband plasmon oscillation (IPO). In the past, IPO has been studied using density-functional theory extensively. [1,2] It was shown that intersubband absorption spectrum "collapses" into a sharp collective mode, which is blue-shifted relative to the subband-edge separation. This phenomenon is known as depolarization shift. More recently, other researchers [3,4] treated both FES and IPO use density matrix approach including Hartree and Fock types of interactions. It was shown [3] that the inclusion of FES leads to a red shift from the blue-shifted spectrum by IPO. As a result, the spectrum peak is between the free-carrier peak and the depolarization-dominated peak. But the spectral shape is dominated by the FES.

Using the density matrix approach in this paper, we treat many-body effects such as depolarization effect, vertex correlation, and exchange self-energy consistently for a two-subband system. We find a systematic change of spectral behavior from FES dominated to ISO dominated features, as QW width or electron density is varied, as shown in Fig.1. Such an interplay between the FES and IPO leads to significant changes in both shape and peak position of absorption spectrum. In particular, we find that a cancellation of the FES and IPO “undress” the resonance responses and recovers the free-carrier features of absorption for semiconductors with strong non-parabolicity such as InAs, leading to a dramatic broadening of absorption spectrum (see the curves for 15 nm well in Fig.1). We also compare the difference in spectral change between GaAs and InAs QWs to illustrate the interplay between collective excitations and non-parabolicity.

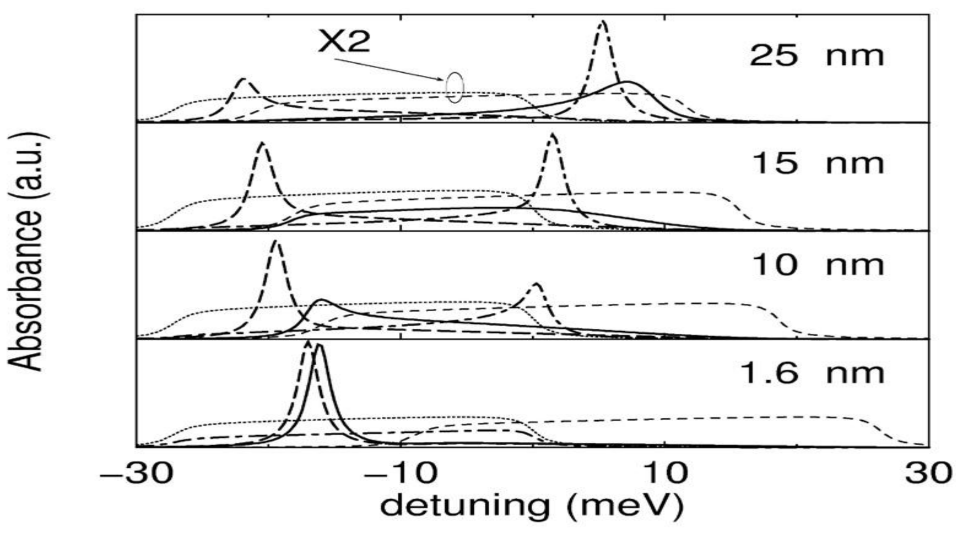

Fig.1: Intersubband absorbance for an InAs QW with varying thickness. Dotted lines represent free-carrier results, while dashed lines include only self-energy contribution. Dot-dashed lines include only depolarization effect, while long dashed lines include both vertex and self-energy contributions. Finally the solid lines include all many-body effects studied in this paper. The electron density is $1.25X10^{12}cm^{-2}$. All dotted and dashed lines were multiplied by a factor of 2.

To show in more detail the spectral change from FES dominated to IPO dominated features, we plot in Figure 1 absorbance of an InAs quantum well with varying width. At narrow well width, the depolarization is negligible, the spectrum with full many-body effects is almost identical to the one with only the exchange interactions (both vertex term and exchange self-energy). With the increase in well width, the peak position of the solid curve moves to the blue side. The FES and IPO become comparably strong. At 15-nm well width, we see that the FES and IPO become equally strong. As a result, the full many-body spectrum (solid line) becomes very broad, and comparable to free-carrier spectrum. In other words, the competition or interplay of strong FES and IPO leads to a strong cancellation of many-body effects and restoration of free-carrier features.

In summary, we have shown that interplay of different collective excitations with varying quantum well parameters leads to an interesting spectral change in both peak position and lineshape. This will not only enhance our understanding of many-body physics in 2D systems, but also allows a more accurate prediction of spectral features for many important infrared applications.

References

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