Photoluminescent Determination of Charge Accumulation in Resonant Tunneling Structures

In a recent Letter[1] Young *et al.* reported measurements of the steady-state electron density in the quantum well of a resonant tunneling diode derived from the intensity of the recombination radiation. We believe that, while their approach may be a credible technique for measuring *relative* electron densities, the calibration required to infer *absolute* densities of electrons in the quantum well is lacking.

To calibrate the integrated photoluminescence (PL) intensity against the areal density n_{2D} of electrons in the quantum well, Young *et al.* considered the zero-bias case. They estimated n_{2D} to be the product of the volume density of donors measured in a similarly grown but much thicker layer (5×10^{14} cm^{-3}) and the width of the quantum well (5×10^{-7} cm), or $n_{2D}=2.5\times10^{8}$ cm^{-2}. The resulting ratio of areal density to PL intensity was then used to infer the density for nonzero voltage biases. This calibration is obtained either by assuming that the equilibrium electron density in the well equals the net donor density, or by assuming that the density of photopumped carriers is equal to this value (resulting in either case in charge neutrality in the well).

We first consider the equilibrium case. The results of a numerical simulation of the structure employed by Young *et al.* are shown in Fig. 1. The conduction-band profile was computed using a self-consistent screening model which assumes that the electron density in the thicker layers is given by a finite-temperature Thomas-Fermi expression and which neglects any electron density in the quantum well. This calculation shows that the band profile near the quantum well is significantly perturbed by the contact potential of the N^{+}-N^{-} junction between layers 2 and 3 of Table I in Ref. 1. This shifts the energy of the resonant state upward from that expected from a flat-band picture, so that it is found 12.3 meV above the Fermi level. If we treat this as a bound state, we may estimate n_{2D} as

$$n_{2D}=(m^{*}/\pi\hbar^{2}\beta)\ln(1+e^{-\beta(E-\mu)}),$$

giving a value of 1.9×10^{-5} cm^{-2} which differs from the estimate used by Young *et al.* by 13 orders of magnitude. This low density and its exponential sensitivity are in no way dependent upon the assumption of a purely bound state; a more elaborate integration over the resonant scattering states would show similar results. We should emphasize that estimating n_{2D} by assuming charge neutrality would be incorrect even if the resonant energy were below the Fermi level. The electron density in the quantum well will be dominated by the effects of the nearby heavily doped layers because the thickness of the structure is comparable to the Thomas-Fermi screening length.

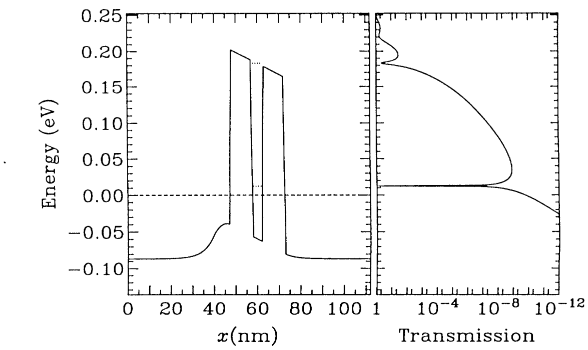

FIG. 1. Numerical simulation of the structure used by Young *et al.* at 4.2 K and for zero bias. The conduction-band profile is plotted to the left, with the Fermi level indicated by the dashed line, and the resonant states indicated by the dotted lines. The quantum transmission coefficient is plotted to the right.

Based upon the computations presented here, we would speculate that the PL observed at zero bias was due to photopumped, rather than equilibrium, electrons. We can imagine two mechanisms which might push the photopumped density toward the charge-neutral condition ($n_{2D}=2.5\times10^{8}$ cm^{-2}). The first is self-consistency of the potential. The above analysis shows that this does not lead to charge neutrality in equilibrium, and it would be extremely fortuitous if it happened to do so away from equilibrium. The second mechanism would be a transition which proceeds via a donor level. Such a situation would presumably have been detected in the experiment.

It thus appears that there is no persuasive reason to believe that the zero-bias electron density in the quantum well under the experimental conditions employed by Young *et al.* equals the donor density. In the absence of a reliable calibration of the PL intensity, the reported values of areal density and resulting characteristic time are not credible.

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[1] J. F. Young *et al.*, Phys. Rev. Lett. **60**, 2085 (1988).