Young *et al.* Reply: The Comment by Frensley, Reed, and Luscombe[1] indicated that there is confusion concerning the procedure used in Ref. 2 to calibrate the photoluminescence (PL) intensity with the absolute electron density accumulated in the well region of a biased double-barrier resonance tunneling (DBRT) structure. The confusion stems from the interpretation of Frensley, Reed, and Luscombe that we used the *equilibrium* density of electrons in the well to normalize the PL intensity data, whereas in fact, as they speculate in their final paragraph, it is the "photopumped" electron population which is used for this normalization.

The crucial point is that the population of electrons contributing to the PL signal with no applied bias voltage, which is the reference density used to scale the relative areas of the PL in order to obtain the density with applied bias, *is* due to the optical excitation and is *not* the same as the equilibrium density of electrons in the quantum well in the absence of laser excitation. As we show below, over the range of laser intensities used to obtain the data in Ref. 2, the *optically generated* electron density is equal to the density of donor impurities, which is *numerically* equal to the *equilibrium* density of electrons *if* charge neutrality had been *assumed*. However, complete equilibrium conditions and an assumption of charge neutrality were neither used nor stated in Ref. 2.

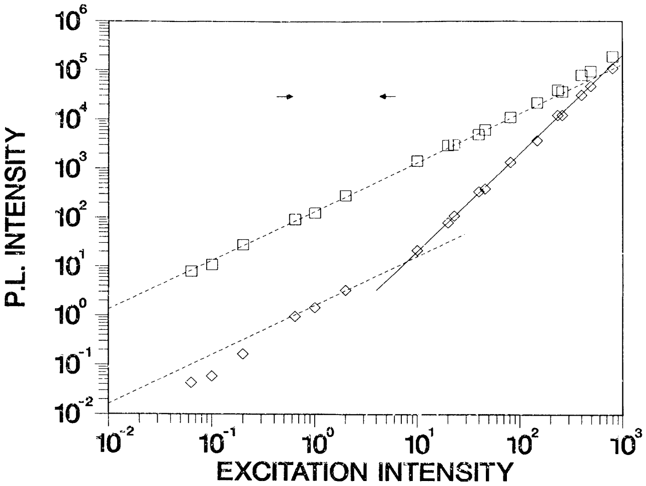

FIG. 1. The peak intensity of the photoluminescence as a function of the incident HeNe laser intensity with 0 V (diamonds) and 0.125 V (squares) applied to the device. The dashed lines have a slope of unity and the solid line has a slope of 2. Unity intensity corresponds to ~ 1 W cm^{-2} incident on the sample. The range denoted by the arrows corresponds to that where the original data were obtained.

Figure 1 shows the intensity of the PL signal as a function of the incident laser intensity (ILI) for zero-V and 125-mV bias applied to the DBRT structure. The data presented in Ref. 2 were obtained for ILI in the range between the arrows, that is, where the ratio of PL intensities with and without the applied bias was independent of the ILI. Taking the PL intensity to be $I_{\mathrm{PL}} \sim (n_e + n_{\mathrm{op}})p_{\mathrm{op}}$, where n_{op} and p_{op} are the photoexcited electron and hole densities and n_e is the electrically injected electron density, then the linear dependence of the PL with applied bias (where $n_e \gg n_{\mathrm{op}}$) implies that p_{op} is a linear function of the incident laser intensity. Thus, for the unbiased case where $n_e = 0$, it follows that the optically excited electron density which contributes to the PL must first increase with ILI, then remain constant in the range denoted by the arrows, and finally increase linearly at higher intensities. The linear behavior at high intensities is expected where the optically injected electron density exceeds the density of impurities in the system and is limited by tunneling through the barriers from the quasibound well state. Although a complete kinetic model for the PL kinetics is not yet formulated, the presence of ionized shallow donor atoms appears to increase the effective lifetime of optically generated electrons at low densities, causing the population to reach a plateau at the donor density as the time constant decreases to that which is *usually* attributed to the quasibound state, neglecting impurity effects. Thus in the range of intensities where a unique ratio of PL intensities is obtained, $I_{\mathrm{PL}}(V)/I_{\mathrm{PL}}(V=0) = (n_e + n_{\mathrm{op}})/n_{\mathrm{op}} \sim n_e/n_d$ where n_d is the density of residual donors in the GaAs, which is precisely the calibration recipe used in Ref. 2.

With regard to the absolute value of the accumulated charge density obtained using the above procedure, we note that it is in excellent agreement with a fully self-consistent solution of Schrödinger's equation for our structure. In addition, further *experimental* evidence supporting the fact that charge does in fact accumulate in the well as described in Ref. 2 has been obtained through magnetotransport measurements on DBRT structures by Payling *et al.*[3]

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