## Comments

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# Comment on "Threshold for optically induced dislocation glide in GaAs-GaAlAs double heterostructures: Degradation via a new cooperative phenomenon?"

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On scratching the surface of a GaAs-GaAlAs heterostructure grown without the usual capping layer and subsequently applying intense optical excitation, it has been found that a threading dislocation results which bows out into the bottom waveguide–active layer interface [Monemar *et al.*, Phys. Rev. Lett. 41, 260 (1978)]. The question has subsequently arisen why the dislocation does not bow out into the active layer–top waveguide interface [Woolhouse *et al.*, Appl. Phys. Lett. 33, 94 (1978)]. In this Comment an answer to this question is presented in terms of the expected minimum-energy configuration of dislocations in a three-layer structure.

In their paper[1] Monemar *et al.* considered GaAs-GaAlAs heterostructures grown without the usual capping GaAs layer (see Fig. 1). The surface of the crystal was lightly scratched and subsequently optically excited. A dense network of dislocations appeared a few microns from the scratch. If the excitation was sufficiently intense, dislocation loops glided away from the network resulting in a dislocation threading from the bottom waveguide layer to the surface of the crystal. It was then observed by means of transmission electron microscopy[2] that the dislocation had bowed out in a ⟨110⟩ direction into the bottom waveguide layer–active layer interface to relieve part of the misfit. The question was then posed why the dislocation does not bow out into the active layer-top GaAlAs waveguide layer interface. In this paper an answer to this question will be presented in terms of the expected minimum-energy configuration of misfit dislocations at the various interfaces.

In a previous paper[3,4] the theory developed by Matthews[5,6,7] to describe the dislocation configuration at the interface of a bicrystal system has been extended to double- and triple-layer systems. The theory involves the setting up of an expression for the total energy of a heterojunction system which

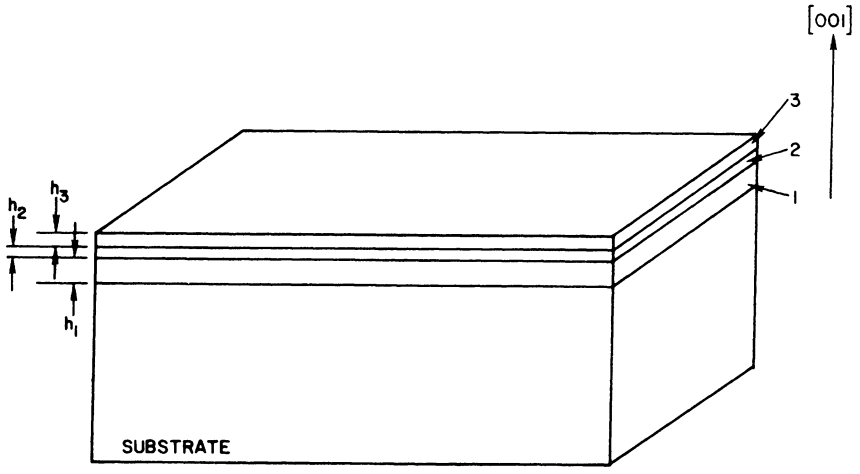


FIG. 1. A typical GaAs-GaAlAs heterostructure. The threading dislocation (see text) bows out into the interface between layers 1 and 2.

 

TABLE I. Sample parameters: $f_1$, $f_2$, and $f_3$ are the misfits between the various layers and $h_1$, $h_2$, and $h_3$ are their thicknesses. (The layers are numbered from the substrate.)

| Wafer | $f_1$ ($\times 10^{-4}$) | $f_2$ ($\times 10^{-4}$) | $f_3$ ($\times 10^{-4}$) | $h_1$ ($\mu$m) | $h_2$ ($\mu$m) | $h_3$ ($\mu$m) |
|---|---|---|---|---|---|---|
| *A* | 5.65 | 5.49 | 5.49 | 3.1 | 0.7 | 0.9 |
| *B* | 7.25 | 7.09 | 7.09 | 5.0 | 0.7 | 1.5 |
| *C* | 7.07 | 6.91 | 6.91 | 4.5 | 0.5 | 0.8 |
| *D* | 7.07 | 6.91 | 6.91 | 3.6 | 0.6 | 0.6 |

is the sum of the coherency strain energy and the strain energy of the dislocations. The thickness of the various layers and the misfits between the materials constituting the layer enter this expression as variable parameters. The minimum-energy configuration of misfit dislocations at the interfaces is calculated by minimizing the total energy with respect to the strains in the various layers and hence obtaining the dislocation densities which are simple functions of these strains. In the development of this theory it has been assumed that sufficient energy is available to activate sources of the dislocations and to keep the dislocations in motion.

In their paper[1] Monemar *et al.* have reported similar results for four different heteroepitaxial structures (see Fig. 1). The sample parameters of these structures which are required in the application of the minimum-energy theory[3,4] are given in Table I.

The similarities in the structure parameters between these four wafers are immediately apparent: Firstly, the misfits $f_1$, $f_2$, and $f_3$ of each wafer are approximately equal and, secondly, in each case the first layer thickness $h_1$ is considerably greater than the second- and third-layer thicknesses $h_2$ and $h_3$. Curves of the variation of the densities of dislocations at the various interfaces with an increase in the third-layer thickness as calculated from the theory of Refs. 3 and 4 are given in Fig. 2 for a typical case.

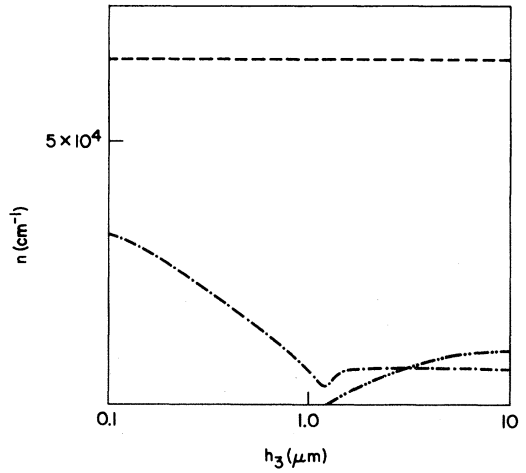


FIG. 2. Semilogarithmic plot of the density of dislocations at interface 1 ($n_1$) (----), interface 2 ($n_2$) (—•—•—•), and interface 3 ($n_3$) (—••—••—••) versus the third-epilayer thickness $h_3$. ($f_1=f_2=f_3=7\times10^{-4}$, $h_1=5$ $\mu$m and $h_2=0.5$ $\mu$m.)

From Fig. 2 it can be seen that for small values of the third-layer thickness the minimum-energy configuration of dislocations is as follows: A high density occurs at the first interface, a somewhat lower one at the second interface, and a zero density occurs at the third interface. Wafers *A*, *C*, and *D*, whose third-layer thicknesses are small, fall into this category.

At a certain critical third-layer thickness, dislocations are introduced at the third interface. Wafer *B* in Table I, whose third-layer thickness is the largest among the four wafers, is thus expected to have dislocations at the third interface. However, this density is expected to be lower than that of the second interface. The actual calculated values of first, second, and third interfacial dislocation densities are given in Table II. (Note that any kinks which appear in the curves of Fig. 2 are due to the method of choosing the cutoff radii of the dislocations.)

The explanation for the observed behavior of the threading dislocations in the optically excited GaAs-GaAlAs heterostructures is thus given as follows: The dislocation does not bow out into the third interface between the active layer and the top waveguide owing to the fact that it is more energetically favorable for it to relieve misfit at the second interface. Although it is most energetically

TABLE II. Densities of dislocations at the first ($n_1$), second ($n_2$), and third ($n_3$) layers. (The layers are numbered from the substrate.)

| Wafer | $n_1$ ($\times 10^4$)/cm | $n_2$ ($\times 10^4$)/cm | $n_3$ ($\times 10^4$)/cm |
|---|---|---|---|
| *A* | 4.66 | 0.25 | 0 |
| *B* | 6.72 | 2.18 | 1.69 |
| *C* | 6.47 | 0.84 | 0 |
| *D* | 6.36 | 1.54 | 0 |

favorable for a dislocation to relieve misfit at the first interface between the substrate and the bottom waveguide, it is believed that in this situation there was insufficient excitation energy available to cause the dislocation loop, from which the threading dislocation arises, to move as far into the crystal as the substrate. This is because most of the exciting laser's light is absorbed in the active GaAs layer and does not reach the lowest interface.

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