Evolution of the Shapes of InAs and InGaAs Quantum Dots

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The exact shape of self-assembled quantum dots is still a controversial subject in the literature, despite the fact that this knowledge is of paramount importance for modeling the energy levels and electron wavefunctions in the quantum dots. We will describe reflection high energy electron diffraction (RHEED), atomic force microscopy (AFM), and transmission electron microscopy (TEM) measurements on both InAs and InGaAs quantum dots grown on (100) GaAs substrates.

Figure 1 shows a RHEED pattern taken along the $[0\bar{1}1]$ azimuth during the growth of $In_{0.44}Ga_{0.56}As$ quantum dots grown using alternating molecular beams of In, Ga, and As_2. The chevrons have an enclosed angle of about 50°. These chevrons have been reported by several groups, always at the growth temperature. However, as the sample is cooled down, we observe that the chevrons along this azimuth dim and eventually disappear at temperatures around 300°C. This suggests that surface diffusion is taking place, even at low temperatures, which modifies the shape of the quantum dots from the shape at high temperatures. AFM and TEM measurements on these uncapped dots show a bimodal size distribution in which the smaller dots are peaked at the top (pyramidal) and the larger dots are flat over their central region (lens-like). The TEM images suggest that several different island shapes are present.

Figure 2 shows a RHEED pattern taken along an [001] azimuth during the cooldown from growth temperature of some InAs quantum dots. For this sample, no chevrons are seen on the $[0\bar{1}1]$ azimuth during growth. In fact, at the growth temperature of 540°C, there is no indication of three-dimensional growth whatsoever. The RHEED pattern does not begin to show the characteristic spot pattern until the substrate temperature has cooled to approximately 365°C. This is further confirmation that surface diffusion is occurring at substrate temperatures that are much lower than the growth temperature of the quantum dots. It is also noteworthy that along this azimuth we observe that there are crossed streaks with an enclosed angle of about 76°. This is distinctly different from the chevrons that are shown in Figure 1, where the streaks only point in the direction of the shadow edge. Finally, we note that these crossed streaks also dim and disappear as the sample is cooled.

In summary, we report on the evolution of the RHEED pattern during quantum dot formation and cooldown. Our results indicate a change in the shape of uncapped quantum dots during sample cooldown and also the formation of quantum dots during sample cooldown.

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Figure 1: RHEED pattern along [0(-1)1] azimuth showing chevrons during growth of InGaAs quantum dots at 510°C.

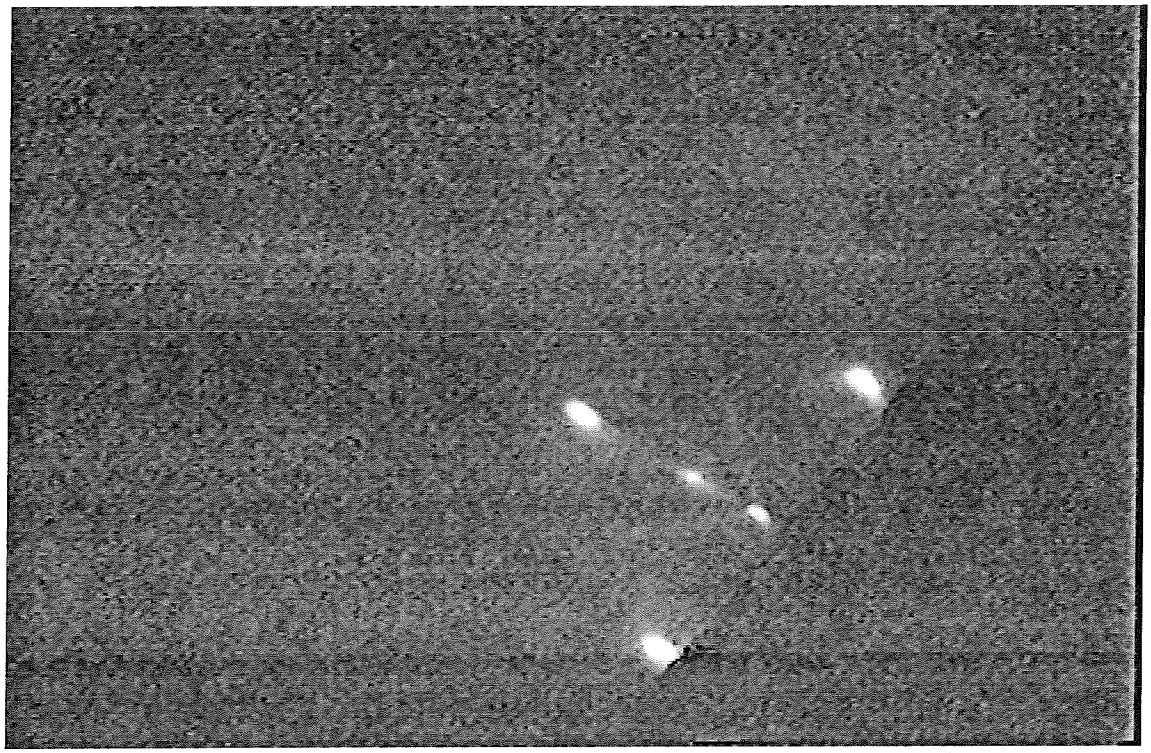

Figure 2: RHEED pattern along [001] azimuth showing crossed streaks during cooldown of InAs quantum dots grown at 540°C.