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Indium Adatom Migration in InAs/GaAs Quantum-Dot Growth

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Islands were grown by Stranski-Krastanow (S-K) mode of MBE at various growth temperatures, and an Arrhenius plot of island density was obtained. An equation for island density was also shown based on a simple model. An activation energy for migration of In adatoms was estimated to be 4.0 eV.

1. Introduction

In spite of recent much effort, the growth mechanism of S-K islands is not yet established, especially concerning the dependence on growth parameters. The present paper deals with the problem.

2. Experimental Method

Two monolayers of InAs were grown by MBE on GaAs (001) substrates at nine growth temperatures T_s between 450 °C and 530 °C. Surface densities of islands were determined by AFM observations.

3. Results and Discussion

AFM images of InAs islands are shown in Fig. 1. Islands of 16-50 nm diameters and 1-7 nm heights are observed. An island size increased and an island density decreased with an increase in T_s. Desorption of In atoms during growth was inferred from AFM images at T_s of 520 °C and 530 °C (Fig.1 (d)).

An Arrhenius plot of island density is shown in Fig. 2. Figure 2 indicates straight line behavior. A fitted line is also shown. Two data for higher T_s indicating In desorption were omitted from fitting. The line in Fig. 2 is right-side up, because the activation energy of Fig. 2 is not an energy barrier for island formation and is an activation energy for migration of In adatoms.

For understanding of the Arrhenius plot of Fig. 2, an expression for island density was given on the assumption that the density is saturated under a constant In flux J. The saturation occurs because islands nucleate no longer when the adatom number in the capture region around an island becomes equal to a number of atoms in a critical cluster n^* [1]. Then, a saturated island density N_s is given by

$$N_s = \left(\frac{N_0 \cdot J}{n^* \cdot \nu} \right)^{1/2} \exp\left(\frac{E_d}{2k_B T_s} \right), \qquad (1)$$

where N_0 is a density of surface In sites, ν is a vibrational frequency of an In adatom, E_d is an activation energy for migration of In adatoms, and k_B is Boltzmann's constant.

An activation energy for migration of In adatoms E_d was estimated to be 4.0 eV from the slope of the fitted line in Fig. 2 using eq. (1). The obtained E_d of 4.0 eV is much larger than reported value of about 1 eV or less [2]. Two reasons for the discrepancy should be considered. First, it is possible that the density was not saturated in the experiment. If this is the case, S-K islands are formed by a kinetic process, and not by a thermodynamic process. Secondly, temperature dependence of n^* was ignored in fitting. It is expected that n^* increases with T_s.

References

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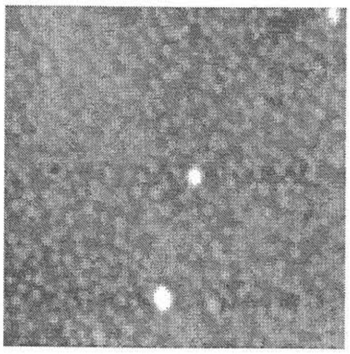
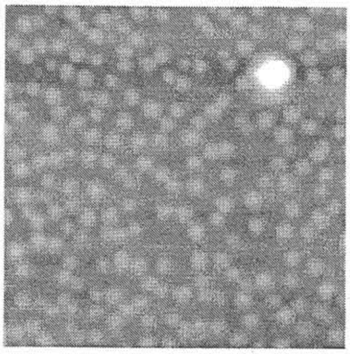
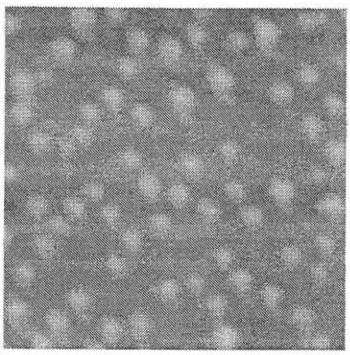


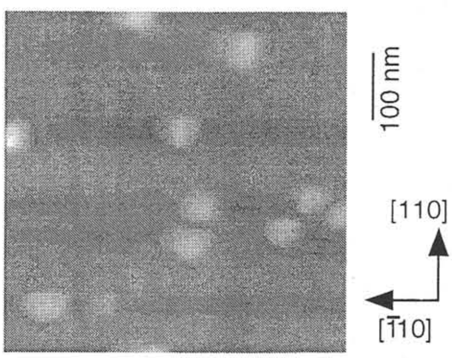
(a) T_s=450°C



(b) T_s=480°C



(c) T_s=510°C



(d) T_s=530°C

FIg. 1 AFM images of InAs islands grown on GaAs (001) surfaces at (a) 450 °C, (b) 480 °C, (c) 510 °C, and (d) 530 ℃.

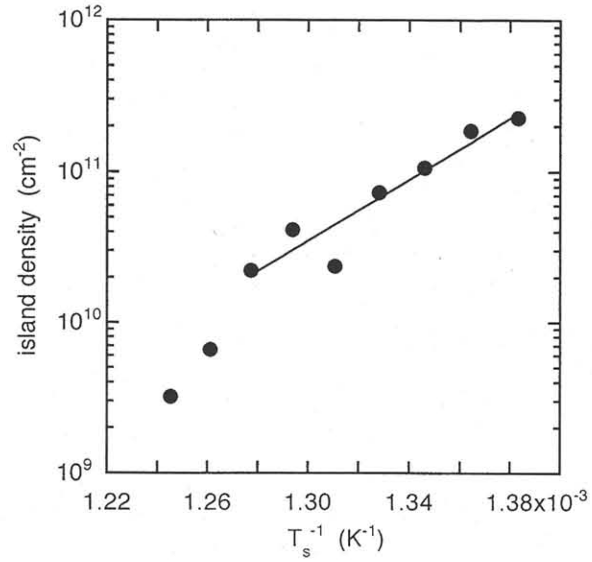


Fig. 2 Arrhenius plot of InAs island densities. A fitted line is also shown. Two data for higher T_s indicating In desorption were omitted from fitting.