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Journal of Crystal Growth 279 (2005) 241–247
JOURNAL OF CRYSTAL GROWTH
www.elsevier.com/locate/jcrysgro

Surface morphology of GaInP buffer layers and its impact on the lateral distribution of self-organized InP islands

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Received 8 January 2005; accepted 12 February 2005
Available online 15 April 2005
Communicated by R. Fornari

Abstract

The surface morphology of GaInP buffer layers mismatched to GaAs substrate is probed to study its impact on the distribution of self-organized InP island. The steps, facet island matrix and mismatch dislocations formed sequentially as Ga content increased in buffer layers. And the lateral distribution of InP island can be controlled efficiently by the steps, island matrix and mismatch dislocation. The island matrix, with about 100nm periodicity, is found to be efficient to obtain InP island lateral distribution with 1μm periodicity on sample 3. The result also shows the dislocation had different functions to control the island distribution along different directions, [110] and [1 $\bar{1}$ 0] directions.

PACS: 68.55.Ac; 68.55.Nq; 81.16.Dn; 81.15.Gh; 81.07.Ta; 42.55.Sa

Keywords: A1. Crystal structure; A1. Stress; A3. Metalorganic chemical vapor deposition; A3. Quantum dot; B2. Semiconducting indium phosphide

1. Introduction

While the lithographic methods [1–3] or scanning probe microscopy (SPM) nanofabrication procedures [4,5] were engaged in semiconductor epitaxy growth for nanostructure as the growth of computing speed, storage density and its application at single-photon communication, self-organized island formation has attracted significant attention because of its compact growth procedures [6–19]. However, although self-organized island formation has been assessed for the island morphology and ordered island array formation,

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doi:10.1016/j.jcrysgro.2005.02.049

much more effort should be made for the self-organized heteroepitaxy to replace the man-made procedures mentioned above, for example, the research about lateral ordering distribution [8–14].

Stress in the self-organized system is very important for the growth of the islands at specific positions because the stress-induced surface could not only dictate the development of a desired morphology, but also affect the nucleation on its surface, including the distribution of the island [12–14], the nucleation mechanism [15,16] and the nucleation place [17]. The effective interactions under stress among steps on vicinal surface could form step bunches [18,19], making them suitable sites for the nucleation of nanometer-sized islands. Such result had been demonstrated by the systems of Ge/Si [20,21], InGaAs/GaAs [22], Si/GaAs [23], etc., and associated with lateral island distribution along the step bunch direction [12,24]. The faceted islands (3D island matrix) would appear on the film surface if the step bunches could not release enough stress between the buffer layer and substrate [14]. The islands mainly formed with {1 0 5} facets and distributed regularly on the film surface. This kind of island matrix would be more regular and apparent if the stress-induced superlattice was employed [8,25]. The dislocation would be inevitable when the spontaneous roughness and 3D island matrix could are not enough to release the stress [26,27]. The dislocation regulations of the self-organized island have been reported at Ge/Si, InP/GaInP systems [14,25,28].

2. Experiments

Here we report our analysis of the buffer layer morphology influenced by stress and the research about its influence on the lateral distribution of InP island grown on such buffer layers. The lateral island distribution has been studied by scaling theories and some kinds of orderliness have been found [28]. But what is the reason that the island regularity was improved when Ga increased in GaInP buffer layers? We therefore made use of our AFM results to analyze the buffer layer morphology, which contains steps, island matrix and dislocations, and found that they are the key elements to control the island lateral distribution. The samples were prepared, as in Ref. [28], and analyzed by AFM. The self-organized InP islands were grown on GaInP layers, whose compositions are $Ga_{0.51}In_{0.49}P$, $Ga_{0.69}In_{0.31}P$ and $Ga_{0.92}In_{0.08}P$, respectively.

3. Results and discussion

3.1. Surface morphology of GaInP buffer layers

Fig. 1 shows the morphologic revolution of GaInP buffer layers with the stress increasing. Table 1 gives the "bare" GaInP surface roughness of the three samples at the place without dislocations. Only steps could be observed on the surface of sample 1, resulting in the very smooth surface (its average roughness is only 0.13 nm). The line profile (see Fig. 1(b)) along [1 1 0] direction shows the regular steps with 5 nm length on sample 1.

The 3D islands (the white squares on sample surfaces) could be observed on the surface of samples 2 and 3 (see Figs. 1(c) and (e)). And with the roughness increasing (average roughness increases from 0.32 nm on sample 2 to 0.47 nm on sample 3), 3D islands formed more regularly and apparently. On sample 3 the regular islands were clearly shown, which are called island matrix [9]. The line profiles of samples 2 and 3 (in Fig. 1) could give us more details. Especially, the regular distribution of faceted islands was demonstrated with about 100 nm periodicity from the island profile of sample 3 (Fig. 1(f)). It was worth pointing out that our experiments result is close to recent theoretical calculations, in which the instability, caused by the misfit between the film and substrate, could yield highly ordered nanocrystals, generating the application potential in quantum dot arrays fabrication [10,11].

The buffer layers of our samples have a thickness of about 110 nm and exceed their corresponding critical thickness greatly [28], therefore, the spontaneous roughness could not release the stress enough, resulting in the formation of dislocation. Fig. 2 shows the regular dislocation distribution both along [1 $\bar{1}$ 0] and [1 1 0] directions on sample 3, whose distances (indicated by