Extended Abstracts of the 1996 International Conference on Solid State Devices and Materials, Yokohama, 1996, pp. 870-871

Proposal of a New Self-Limited Growth and Its Application to the Fabrication of Atomically Uniform Quantum Nanostructures

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Although great progresses have been achieved toward the realization of high quality semiconductor quantum wires (QWRs) and quantum dots (QDs) in recent years, the density and uniformity of these quantum nanostructures fabricated by the present methods are still far from that required for the realization of high performance optoelectronic devices. In this paper, we propose a completely new self-limiting mechanism of semiconductor crystal growth by which atomically uniform quantum nanostructures is believed to be fabricated easily independent of structure density.

This technique is basically based on flow rate modulation epitaxy (FME) [1] which was first applied to the low temperature growth of high quality QWRs by Wang et al.[2]. Figure 1 shows the typical gas flow sequence of FME. The mechanism of the new self-limiting effect is schematically described in Fig.2 using the [0 $\bar{1}$1] oriented V-grooved substrate as an example. The initial V-groove bottom is terminated with As atoms after the AsH_3 flow period (Fig.2(a)), but it will change to a Ga-terminated surface when just 1ML of GaAs was grown at the V-groove bottom during the TEGa flow period (F.g.2(b)) because the AsH_3 partial pressure during TEGa flow and H_2 purge periods was reduced to a value not sufficient for the formation of epitaxial layers. We consider what will happen if we further supply TEGa to the Ga-terminated substrate surface. Ga atoms on a Ga-terminated surface is considered to be considerably longer than that on an As-terminated surface. Therefore, it is expected that the excess Ga atoms will migrate through the (111)A side wall facets to the (001) flat facet where As dangling bonds are still remained due to the slow growth rate of the (001) flat facet compared with that on the V-groove bottom (Fig.2(b)). As a result, no GaAs will be grown further on the 1ML GaAs (Fig.2(c)), that is, the realization of a completely new type of self-limited growth.

The above idea was confirmed by growing GaAs QWRs on a 2μm-pitched V-grooved GaAs substrate at various TEGa flow rates at 640°C. Figure 3 shows the growth thickness at the center of the V-groove bottom per cycle as a function of TEGa flow rate. It can be seen clearly that self-limited growth was indeed achieved at a considerably wide TEGa flow rate region. We call this new self-limiting effect as migration induced self-limiting to distinguish from the adsorption saturation induced self-limiting mechanism used in atomic layer epitaxy (ALE).

The current lithography and etching processes inevitably introduce some size fluctuations to initial patterned substrate. This initial substrate size fluctuation will eventually lead to the inter-structure size fluctuation of the grown nanostructures by the conventional selective growth technique. However, atomically uniform nanostructures is expected to be achieved easily using the self-limited growth proposed here by supplying an adequate amount of TEGa.

Finally, We want to point out that this method is of course not limited to the V-grooved substrate but can be applied to various substrate configurations, providing that there is a slow-growing-facet to absorb the excess atoms. Furthermore, this new method is considered be able of producing quantum nanostructures with ultrahigh crystalline quality since it is based on the control of surface migration, but not adsorption saturation as in the case of ALE. This new growth technique is expected to contribute greatly to the fabrication of device-quality quantum nanostructures.

References 1) N.Kobayashi et al., JJAP 24 (1985) L962.
2) X.L.Wang et al., APL 66 (1995) 1506. 67 (1995) 804. 67 (1995) 3629.

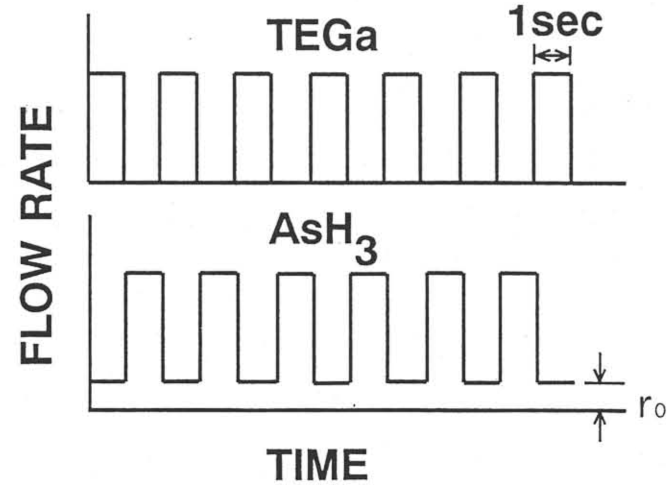

Fig.1 Typical gas flow sequence of FME growth

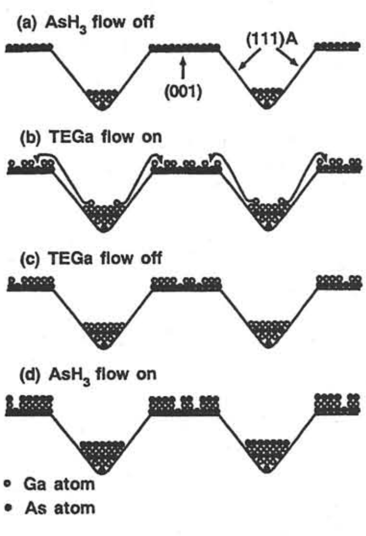

Fig.2 Schematic illustration of the migration induced self-limiting mechanism

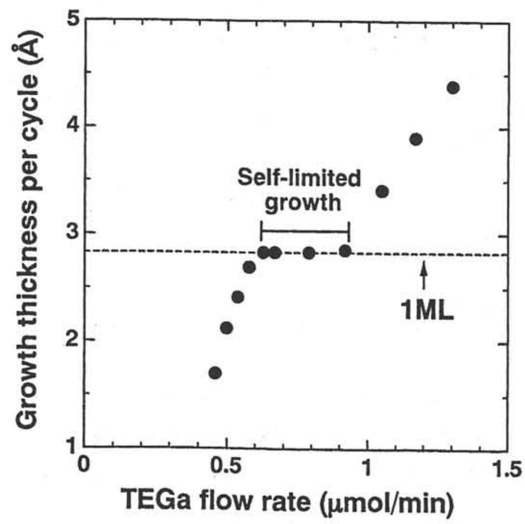

Fig.3 GaAs growth thickness per cycle as a function of TEGa flow rate