SEMICONDUCTOR A3B5 NANOWHISKERS GROWN BY MBE: GROWTH AND KINETIC THEORY

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Semiconductor nanowhiskers (NWs) are wire-like nanocrystals with high (10-100) lendth/diameter ratio and the diameter of several tens of nanometers. Unique structural properties of NWs make them very attractive in numerous applications including optoelectronics, microelectronics, field emission devises and analytical chemistry. One of the important issues in physics and technology of NWs is the development of reliable nanofabrication technique with controllably structured NWs. Strongly non-equilibrium conditions and a high surface diffusivity of ad-atoms during molecular beam epitaxy (MBE) may bring new features into the traditional mechanism of the so-called “vapor-liquid-solid” (VLS) growth of whiskers. In this work we investigate theoretically and experimentally the formation mechanisms and physical properties of GaAs NWs grown by MBE on the GaAs(111)B surface activated by Au growth catalyst. We show that diffusion-induced contribution to the NW growth rate increase the observed length of sufficiently thin GaAs NWs in order of magnitude.

In the theoretical model of NW formation we consider (i) adsorption and desorption processes on the surface of liquid drop, (ii) crystallization of supersaturated liquid alloy on the crystal surface under the drop, (iii) the growth of non-activated surface and (iiii) the diffusion flux of ad-atoms from the surface to the NW top. The model can systematically handle the combined growth kinetics of NWs by conventional “vapor-liquid-solid” mechanism and by the diffusion-induced mechanism. The main characteristics of NW growth are obtained as functions of the drop diameter and MBE growth conditions.

Experimentally, MBE growth of NW includes 3 stages: deposition of thin Au film on a GaAs surface, thermal formation of Au-Ga eutectic droplets and Au-activated GaAs or AlGaAs NW growth. The surface is investigated by scanning electron microscopy (SEM). Fig. 1 shows SEM image of the sample grown at d_{Au} (Au film thickness) = 1.0 nm, H (GaAs average thickness) =500 nm, T (substrate temperature) = 585^0C and W (GaAs growth rate) = 1 ML/s and comparison of experimental and theoretical length/diameter dependencies obeys the simple 1/D dependence within the whole range of NW lengths and diameters. Similar dependencies characterize AlGaAs NWs. We may therefore conclude that the MBE growth of A3B5 NWs on the GaAs(111)B surface in a wide range of growth conditions implies the domination of the diffusion induced growth. Careful optimization of the growth conditions (W, T, As/Ga fluxes ratio etc.) allowing us to fabricate uniform arrays of standing GaAs NW having up to 15 mkm length and > 100 length/diameter ratio (Fig.2a) grown at d_{Au} = 0.6 nm, H =1500 nm, T = 585^0C and W = 1 ML/s. GaAs NW can also be fabricated on GaAs(100) surface (Fig. 2b) with preferential orientation of them along <110> directions.

Different possible applications and properties of A3B5 are discussed.

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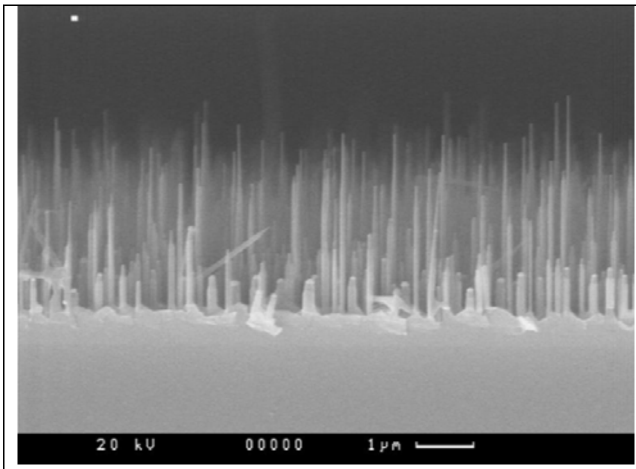
Figures:



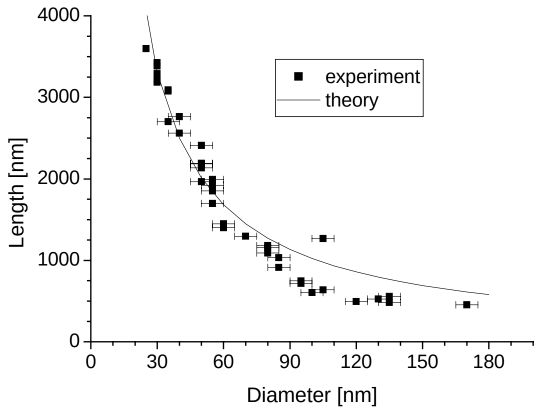


Fig. 1. SEM image, comparison of experimental and theoretical length/diameter dependencies for GaAs NWs

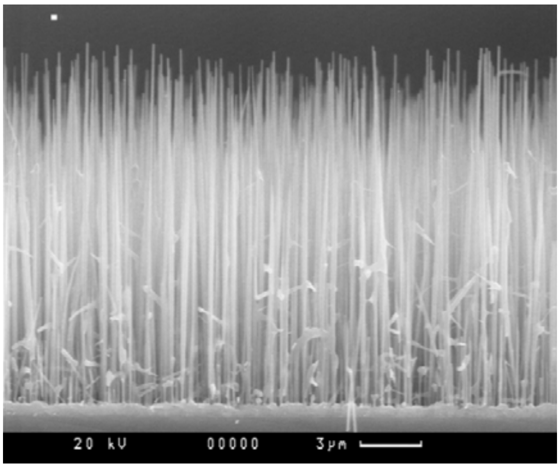


Fig. 2a. Optimized GaAs NW.

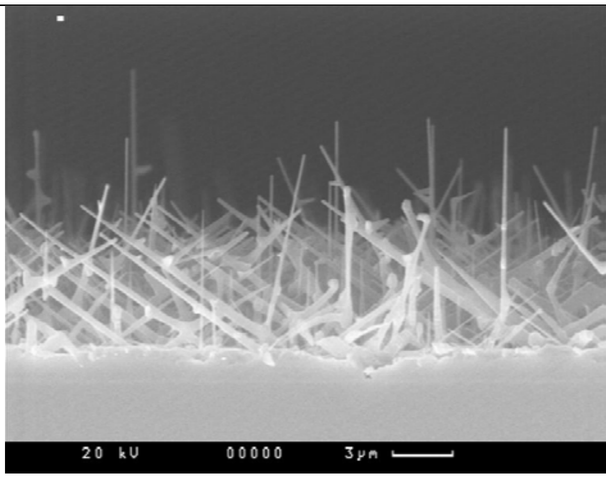


Fig. 2b. GaAs NW grown on GaAs(100) surface.