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Selective Growth of Gallium Arsenide on Germanium Fins with Different Orientations formed on 10˚ Offcut Germanium-on-Insulator Substrate

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ABSTRACT

Heterogeneous integration of high-quality GaAs on Ge fins with different orientations was demonstrated for the first time using Metal Organic Chemical Vapor Deposition (MOCVD). Anti-Phase Domain (APD) formation was effectively suppressed using a substrate with 10˚ offcut. Through extensive characterization with Secondary Electron Microscope (SEM) and Transmission Electron Microscope (TEM), the evolution of GaAs facets with Ge fins rotation is successfully captured and described in a model. This enables the engineering of preferred channel surface orientation for high-mobility III-V MOSFETs.

INTRODUCTION

High mobility Germanium (Ge) and III-V compound semiconductors are promising candidates to replace Si as the channel material in metal-oxide-semiconductor field-effect-transistor (MOSFET) for high speed and low power logic application. Recently, nanoheteroepitaxy of GaAs on Ge fins [1,2] has emerged as a promising integration scheme that enables co-integration of III-V(GaAs) NFET and Ge PFET on Si platform. However, there are many challenges involving GaAs growth on Ge which include growing high quality and APD-less GaAs on Ge, achieving good selectivity, improving line edge roughness and understanding of GaAs facet formation on Ge fins.

In this paper, MOCVD of high quality and APD-less growth of GaAs on 10˚ offcut Ge fins with different orientations was achieved. The effect of substrate tilt and fin rotation on the facet evolution was studied and modeled. This is critical for achieving superior MOS/MIS interface quality and higher electron mobility since the surface orientation determines the $\underline{D_{it}}$ and roughness scattering characteristics [3].

GROWTH AND CHARACTERIZATION

A 10^o offcut GeOI wafer with 50 nm Ge on 100 nm buried oxide (BOX) was used as the starting substrate. 20 nm SiO2 was initially sputtered as hardmask. Fin patterns oriented from 0˚ to 45˚ with respect to the GeOI <011> flat were subsequently defined using E-beam Lithography (EBL). This is followed by dry etching and hardmask removal as illustrated in Fig.1. Rapid Thermal Oxidation (RTO) was then used to smoothen the sidewall of the fin [Fig. 2(a)]. Next, the sample was treated with cyclic DHF/H_2O cleaning before being loaded into AIXTRON 200 MOCVD chamber for GaAs growth at a temperature of 650 ˚C and a pressure of 75 torr with III/V TrimethylGallium (TMGa) and TributhylArsenic (TBAs) gas flow ratio of 15 and growth for 600 s.

RESULTS AND DISCUSSION

The as-grown GaAs on Ge fins [Fig. 2(b)] are faceted as depicted by the cross-section TEM image taken along line A-A` [Fig. 2(c)]. High Resolution TEM (HRTEM) at the GaAs/Ge interface at the top and side of the fins [Fig. 3] reveals good crystalline quality. No observable defects were detected.

In general, the Wulff model [4] may be applied to predict the epitaxial surface shape. Growth facets on a convex substrate tend to be dominated by slow growing facets [5]. For example, GaAs grown on an infinitesimal small seed would result in Equilibrium Crystal Shape (ECS) which terminates with {110}, {111}A and {111}B surfaces, which are the slow growing facets [6,7], as shown in Fig. 4. It is interesting to note that the cross-section in any slicing plane which cuts through the center of ECS and normal to substrate surface is outlined by slow growing facets. Therefore, by extending the cross-section along its normal direction, a fin with facets predicted by Wulff model can be obtained. In other words, if a specific shape of ECS for an experiment is known, it can be used to predict the GaAs facets on various fin orientations.

In order to generate the ECS, the growth rates at different crystal directions are required. We modeled all the possible ECS facets inclination angles with respect to GeOI {811} surface as a function of fin orientation in Fig. 5. Using Fig. 5, the GaAs facets on a particular Ge fin orientation can be explicitly identified based on their inclination angles. A good fit between the model and experimentally extracted inclination angles (plotted as square boxes) is achieved.

With the GaAs facets for various Ge fins identified, the growth rate is extracted using parallel projection of facet plane to Ge fin edge [Fig. 6(a)]. The growth rate at various crystal orientations is plotted in Fig. 6(b). In our experiment, we obtained the growth rate ratio for {811}:{111}A:{110}:{111}B to be 19: 7.8:11:2.

Using the extracted experimental growth rates for different facets, the ECS for this experiment is constructed and shown in Fig. 7(a). The predicted cross-sections for fin orientation θ = 0˚ to 45˚ on ECS are compared with the experimental data, showing a good match [Fig. 7(b)-(c)] .

CONCLUSION

Selective growth of GaAs on Ge fins formed on 10˚ offcut GeOI substrate was demonstrated. The dependence of the GaAs facets with fin orientation was modeled. The GaAs facets are identified based on their inclination angles with respect to GeOI surface and the growth rate of each facet is extracted. The growth rate ratio for {811}:{111}A:{110}:{111}B was found to be 19: 7.8: 11: 2.

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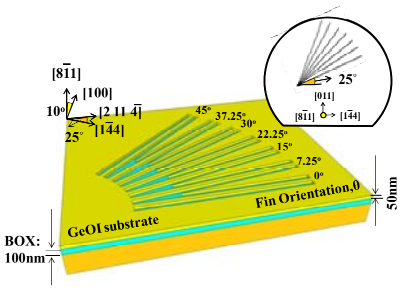

Fig. 1. Fins with different orientations (θ = 0° to 45°) are defined on a 10° Offcut GeOI substrate.

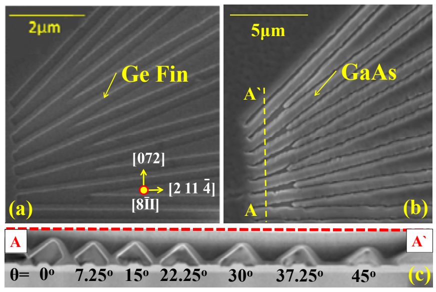

Fig. 2. SEM image of (a) Ge fins before growth and (b) GaAs on Ge fins after growth. (c) TEM cross section along A-A` shows a faceted growth of GaAs on Ge fin.

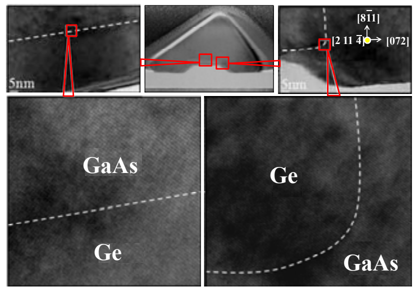

Fig. 3. HRTEM confirms the good crystalline quality of GaAs grown on a Ge fin. Zoom in views of the GaAs/Ge interface at the top and side of the fin is also shown.

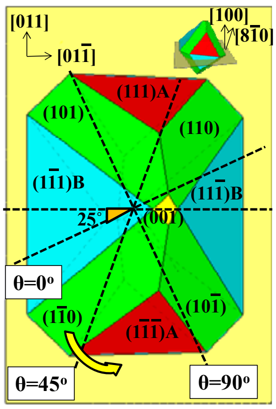

Fig. 4. Equilibrium Crystal Shape (ECS) showing the facets formed when growth is done on an infinitesimally small seed. The slow growing facets are {110}, {111}A and {111}B. ECS predicts the GaAs facets in our fin structures. Inset shows a tilted (10˚ offcut) ECS. Cut-plane through the ECS center perpendicular to the fin orientation θ (mark by dotted lines) predicts the GaAs facets on the θ oriented fin.

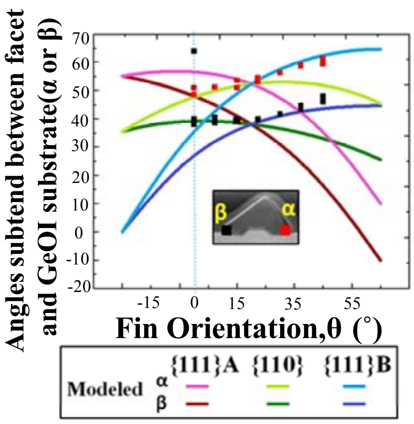

Fig. 5. Angles α and β subtended between facet faces and GeOI {811} surface as a function of fin orientation. Measured angles from TEM are plotted as solid symbols, and simulated angles are plotted as lines.

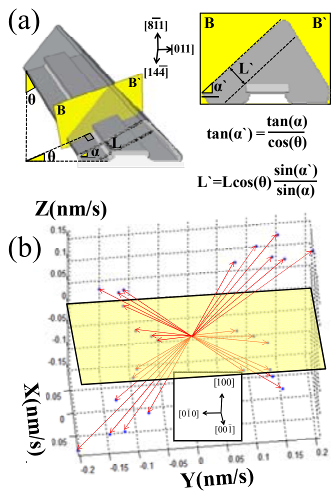

Fig. 6. (a) Method to extract growth rate in a direction perpendicular to facet plane. Growth rate is proportional to *L'*. (b) Growth rate of GaAs in various crystal orientations. The ratio of growth rates of {811}:{111}A:{110}: {111}B is measured to be 19:8:11:2.

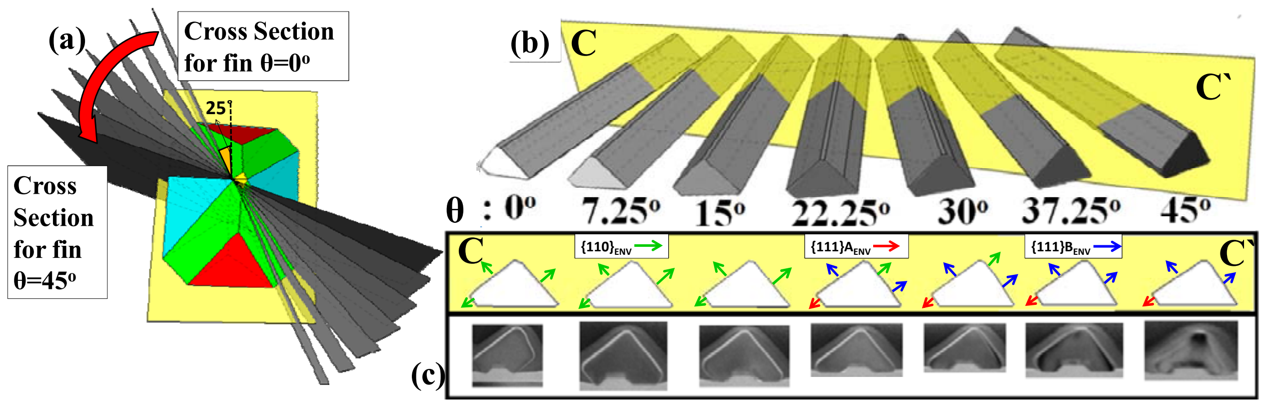

Fig. 7. (a) Modeling of GaAs facets formed on various fin orientations using ECS constructed using growth rates extracted from our experiment. Cross-sections of fin orientated from θ = 0˚ to =45˚. (b) Resulting cross-sections are used to reconstruct the fins, and (c) GaAs facets seen on the cross-section along C-C` which correspond to the TEM cross section A-A` [Fig. 2.] are compared with the experiment. The modeled GaAs facets match well with the experiment. GaAs facets from θ=0˚ to θ =15˚ are enveloped by {110} while GaAs facets from θ=22.25˚ to θ=45˚ are enveloped by {111}B.