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ESRF

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office via the User Portal:

https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do

Reports supporting requests for additional beam time

Reports can be submitted independently of new proposals – it is necessary simply to indicate the number of the report(s) supporting a new proposal on the proposal form.

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Deadlines for submission of Experimental Reports

- 1st March for experiments carried out up until June of the previous year;
- 1st September for experiments carried out up until January of the same year.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	**Experiment title: X-ray diffraction q space mapping of a-plane alpha gallium oxide grown on sapphire substrate**	**Experiment number**: MA3030
Beamline:	**Date of experiment**: from: 15.06.2016 to: 20.06.2016	**Date of report**:
Shifts:	**Local contact(s)**: Nathalie Boudet	*Received at ESRF:*

Michael Hanke, Martin Schmidbauer, Zongzhe Cheng

Report:

Introduction

Ga_2O_3 is a transparent semiconducting oxide (TSO) with fascinating optical and electrical properties. It covers a band gap between 4.7 eV and 5.3 eV, very closely related to its five polytypes (α throung ε). Due to the large value among all TSOs, it is considered as a promising candidate in various applications such as deep UV photodetectors, high power electronics and gas sensors. On the way to commercial applications there are, however, still several issues that need to be addressed, especially the requirement for single-phase formation.

Experiment

The a-plane sapphire substrate is loaded in a plasma-assisted MBE with indium bonding on a piece of silicon. Except for the 700 ºC substrate temperature, the growth condition remains the same: T_{ga}=900ºC, flux of gallium=2E-7mbar, O_2 flux=1sccm, plasma power=300W, background pressure=3E-6mbar. The estimated growth rate is around 0.4Å/s and the growth time is set to be 86 seconds and 260 seconds. After the growth, the layers are characterized by AFM to probe the surface morphology and then checked at BESSY II by the synchrotron radiation beam line U125-2_KMC with the photon energy of 10KeV.

The [11.0] crystal truncation rod (CTR) of the α-phase Ga_2O_3 layer, as shown in figure 1 (A), has the same scale of the full-width-at-half-maximum (FWHM) with the single crystal Al_2O_3 substrate, 0.014° and 0.012°. The narrow FWHM of the Ga_2O_3 layer can be explained by an ideal stacking of the atoms in the layer with rare stacking faults and misorientation in the specular direction. The grazing incidence diffraction (GID) in [00.1] direction probes the in-plane crystal property of Ga_2O_3 layer. The FWHM of the Ga_2O_3 (00.6) peak is 1.129°, 56 times larger than the FWHM of the substrate. The broad FWHM can be explained by the in-plane

misorientation of the nano-grains. According to the Scherrer equation, with a dimensionless shape factor of 0.9, the mean-grain size is about 5.7nm. Compared with the structure of the ideal α-phase Ga_2O_3 bulk crystal, the epilayer is relaxed in both specular [11.0] direction and in-plane [00.1] direction. So the broad FWHM in the in-plane direction is mainly caused by the in-plane misorietation of the nano-grains but not strain. Both AFM and SEM measurement on the surface of the epilayer show a hilly structure.

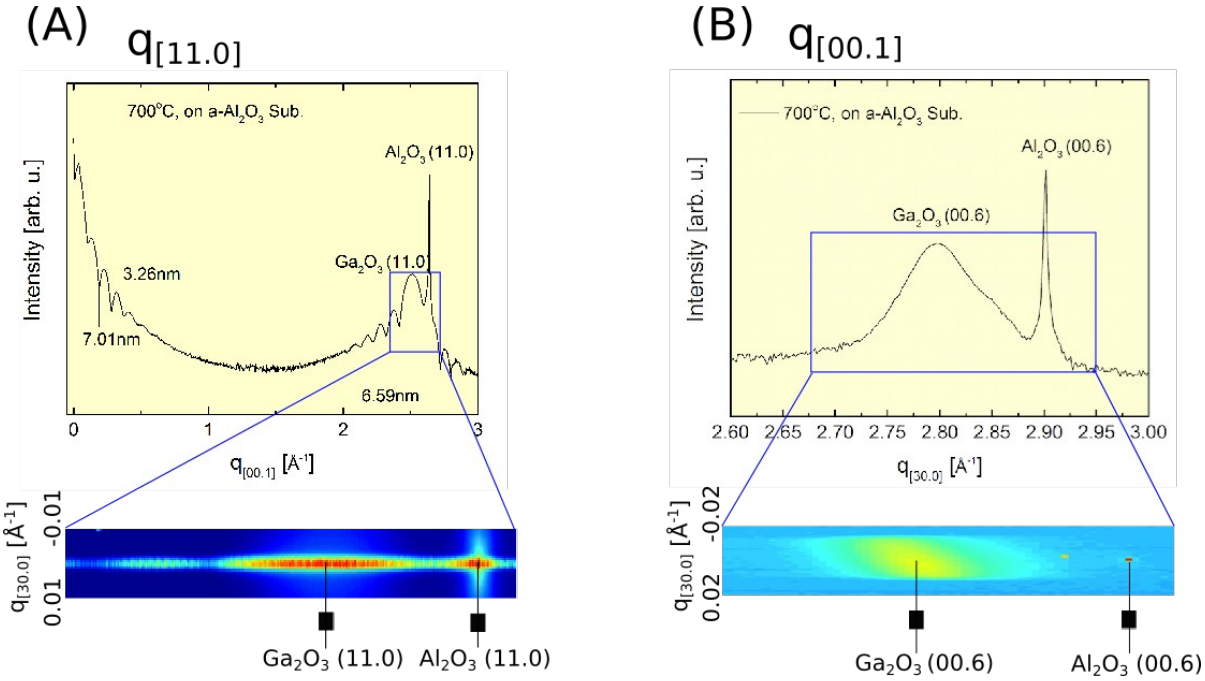

Figure 1. (A): the out-of-plane CTR along the [11.0] direction in the reciprocal space, the (11.0) diffraction peak of α-gallium oxide is shown on the left side of the aluminum oxide (11.0) peak. (B): The GID in the (00.1) direction of the substrate shows the in-plane (00.1) diffraction from both the substrate and the epi-layer.

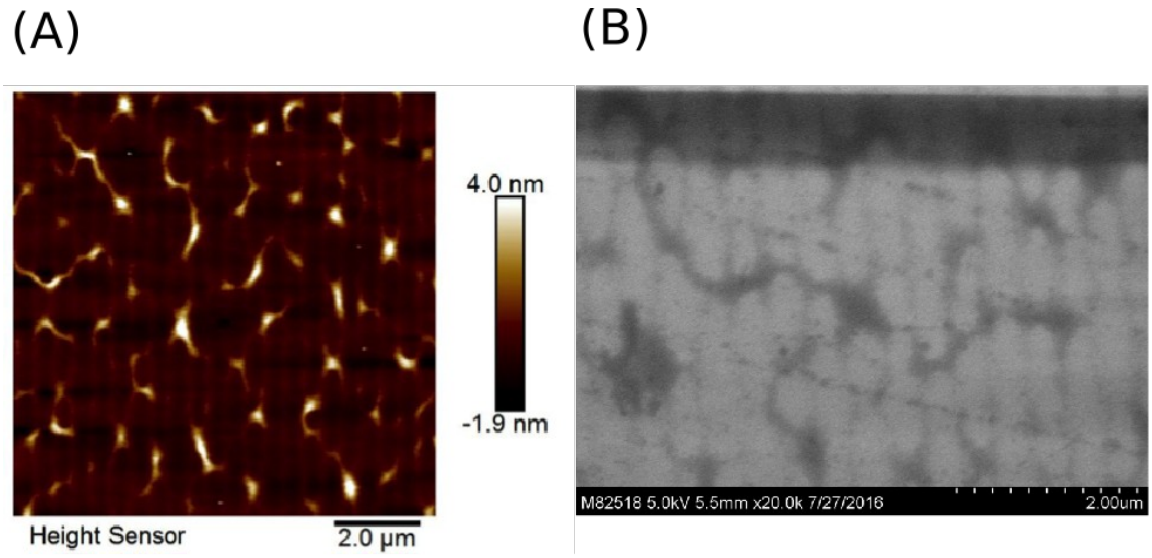

Figure 2. AFM and SEM on the surface of the α-phase Ga_2O_3 layer.

The thickness of the α-phase Ga_2O_3 layer is 6.59nm as indicated by the [11.0] diffraction fringes. However, on a c-plane sapphire substrate, the α-phase Ga_2O_3 layer is only stable in the first 2nm either grown by MBE or PLD or MOVPE, and subsequently transfer into the thermodynamically stable β phase. Therefore, it seems like that the α-phase Ga_2O_3 grows more stable on a-plane sapphire substrate. The mismatch in the c plane is just half of the mismatch in (11.0) plane, 3% to 5.6%, which causes smaller in-plane strain in the (11.0) Ga_2O_3 layer growth.

Summary and outlook

The α-phase Ga_2O_3 can be grown on a-plane sapphire substrate with very high crystal quality in respect of the out-of-plane CTR. Since there is no phase transfer from α-phase Ga_2O_3 to β-phase Ga_2O_3, it seems like the α-phase Ga_2O_3 has more stable growth in [11.0] than [00.1] direction. The in-plane GID shows large FWHM of the RC and AFM and SEM indicates a hilly surface, however these could be improved by further study in the MBE growth.

The a-plane sapphire substrate may give us a chance to produce high quality single crystal α-phase Ga_2O_3 thin film for further study on the property of α-phase Ga_2O_3. With the HR-XRD in a synchrotron radiation facility, it would be interesting to grow α-phase Ga_2O_3 layer with different thickness from several mono layers to tens of nanometers, in order to study the strain relaxation process in the Ga_2O_3 thin film. Besides that, the influence of the growth conditions on the size of the in-plane nano-grains should also be investigated trying to understand the growth mechanism in the α-phase Ga_2O_3 and subsequently achieve the growth of single crystal α-phase Ga_2O_3.