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Optical in-situ monitoring system for simultaneous measurement of thickness and curvature of thick layer stacks during hydride vapor phase epitaxy growth of GaN

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ABSTRACT

For improved real-time process control we integrated a novel optical in-situ monitoring system in a vertical reactor for hydride vapor phase epitaxy (HVPE) growth of gallium nitride (GaN) bulk crystals. The in-situ monitoring system consists of a fiber-optical interferometric sensor in combination with an optimized differential measuring head. The system only needs one small optical path perpendicular to the center of the layer stack typically consisting of sapphire as substrate and GaN. It can handle sample distances up to 1 m without difficulty. The in-situ monitoring system is simultaneously measuring the optical layer thicknesses of the GaN/sapphire layer stack and the absolute change of the distance between the measuring head and the backside of the layer stack. From this data it is possible to calculate the thickness of the growing GaN up to a thickness of about 1000 μm and the absolute change in curvature of the layer stack. The performance of the in-situ monitoring system is shown and discussed based on the measured interference signals recorded during a short-time and a long-time HVPE growth run.

1. Introduction

The Hydride Vapor Phase Epitaxy (HVPE) is a leading method to produce high quality large-area gallium nitride (GaN) bulk crystals [1–5]. Usually "foreign" substrates such as Metal Organic Vapor Phase Epitaxy (MOVPE) GaN layers on c-plane sapphire are used as seeds for the hetero-epitaxial growth of GaN crystals by the HVPE method. In this article this layer stack consisting of the sapphire substrate with the MOCVD seed layer on which the thick HVPE-GaN is grown will be called layer stack. The large lattice mismatch [1,6] and the difference in the thermal expansion coefficients between GaN and sapphire [7–9] and also dislocations lead to complex stress states in the layer stack which cause curvature and sometimes even cracking of the layer stack during or after the growth run [10–14]. Therefore, the curvature of the layer stack is a very important parameter for the process control during hetero-epitaxial growth of GaN.

In contrast to most MOVPE reactors and a few special horizontal HVPE systems [15,16] commercial available vertical HVPE reactors are usually not equipped with an in-situ measurement system for determination of the curvature and the thickness of the growing GaN crystal. The principal reason for this is the missing optical access to the surface of the growing GaN crystal from at least two opposed positions in most vertical HVPE reactors. The optical access is needed for laser reflectometry based commercial in-situ curvature measurement systems [17]. But, usually heater, insulations and other mechanical parts surrounding the layer stack in the HVPE reactor are blocking the needed optical paths. On the other hand, commercial sensor systems based on interference mainly allow layer thickness measurements, but are restricted in terms of displacement and wafer bow measurements because of the limitation of the measurement distance (few cm) and of the effective measuring range (few mm).

To compensate for these drawbacks we developed and integrated a novel optical in-situ monitoring tool in our HVPE reactor which only needs one small optical path perpendicular to the center of the layer stack. The in-situ monitoring system can measure the curvature and the thickness of the growing GaN simultaneously from the backside of the layer stack. In comparison

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to curvature measurement systems based on laser reflectometry this in-situ monitoring tool is able to measure curvature and thickness of rough GaN layers up to a thickness of about 1000 μm and is not limited to a maximum layer thickness of about 100 μm as for example systems based on laser reflectometry [18].

2. Experimental

The novel in-situ monitoring system in the vertical HVPE reactor consists of a commercially available fiber-optical interferometric sensor "CHRocodile IT500 RW" from Precitec Optronik GmbH which is normally used for non-contact measuring of sample (e.g. wafer) thickness, in offline and inline wafer inspection systems from a small distance. This sensor needs some modifications to determinate not only the thickness but also the curvature of the GaN/sapphire layer stack and the growing GaN layer during the HVPE process, because the distance between the sensor and the layer stack is very large (about 100 cm). Furthermore, we expect variations in the measurement distance caused by thermal expansion of the different components during heating and by rotation of the substrate holder. These variations have to be compensated by the monitoring system. Therefore, we further developed the interferometer with an optical assembly to a differential measuring head as shown in Figs. 1 and 2, which facilitates sample displacement and therefore curvature measurements. The differential measuring head consists of three adjustable metallic gold mirrors and one appropriate lens which focus the light beams on the backside of the layer stack and on the substrate holder in a distance of 85 cm, respectively. As light source the measurement system uses a super luminescent light emitting diode (SLED) with maximum peak intensity at a wavelength of 1550 nm (near infrared, NIR) with a spectral bandwidth (full width at half maximum, FWHM) of about 40 nm. For visualization during beam adjustment on the layer stack backside the system also includes a visible laser diode emitting at a wavelength of 650 nm (red).

The optical paths of the light beams (see Fig. 1) can be described as follows: the narrow-band light of the SLED integrated in the optical interferometric sensor gets to the lens of the differential measurement head via a single-mode fiber optical waveguide. The lens focusses the beam to a distance of about 85 cm which corresponds to the optical path distance to the backside of the layer stack and the substrate holder backside, respectively. Behind the lens the primary beam (dark red in Fig. 1) is reflected at mirror 1 by 90°. Mirror 2 splits the primary beam into two beams: the main beam (dark red) and the reference beam (bright green). The difference between these two path lengths is measured via their interference. The reference beam is needed to minimize failures in the distance measurement caused by e.g. the thermal expansion of the HVPE reactor. The main beam (dark red) is adjusted by mirror 1 through the antireflection coated viewport to the backside of the GaN/sapphire layer stack and passes a hole in the center of the substrate holder which is 5 mm in diameter. After reflection of the reference beam (bright green) at mirror 2, it is directed by mirror 3 through the viewport parallel to the path of the main beam to the backside of the substrate holder where a reflecting disc made of lapped sapphire is mounted. The distance x_1 between mirrors 2 and 3 must be adjusted to be nearly equal to the distance x_2 between the backside of the layer stack and the substrate holder to minimize the optical path difference between the main beam and the reference beam and therefore to comply with the maximum interferometric measurement range of the sensor of 5600 μm.

The main beam (dark red in Fig. 1) is partially reflected at the backside of the GaN/sapphire layer stack, at the boundary surface

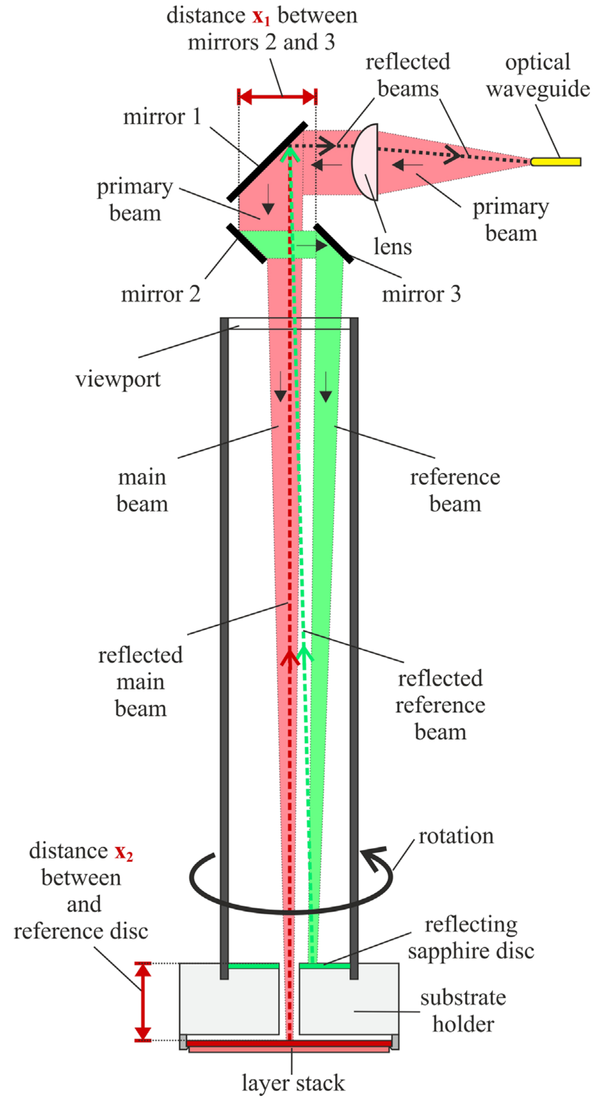

Fig. 1. Schematic diagram of the optical path of the differential measuring head. The optical path of the different light beams is described in detail in the text. The distance x_1 between mirrors 2 and 3 should be nearly equal to the distance x_2 between the layer stack backside and the reflecting reference disc mounted on the backside of the substrate holder (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.).

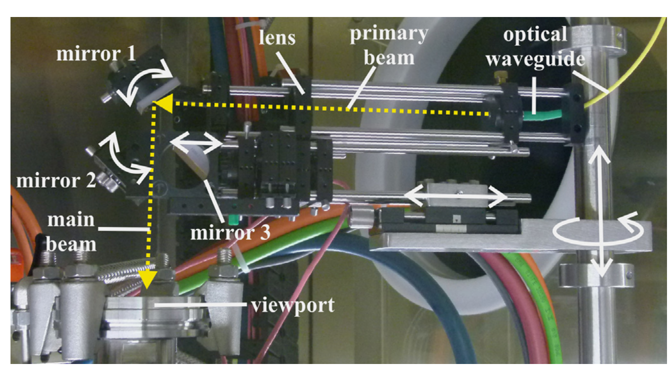

Fig. 2. Photograph of the rotatable and linear moveable mounted differential measuring head. The optical path of the primary beam and the main beam is illustrated by yellow dashed arrows. The white solid arrows show the possible rotary and linear variations of parts of the measuring head to adjust the beams to the desired positions at the layer stack backside and the substrate holder backside, respectively (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).