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Piezoelectric coefficient of InN films prepared by radio-frequency sputtering

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Abstract

An interferometric method has been used to measure the piezoelectric coefficient d_{33} in indium nitride films deposited by radio-frequency sputtering on borosilicate glass coated with gold. This low temperature growth technique has the advantage of being able to produce samples for piezoelectric measurements where the InN film is grown directly on an Au metal back contact, allowing the accurate measurement of the piezoelectric coefficient of the InN layer without any parasitic series resistance. The InN growth conditions are described, and both crystal and optical characterizations of the film are presented. The measured value of the coefficient was found to be 4.0 ± 0.1 pm V^{-1}.

Keywords: Piezoelectric coefficient; Radio-frequency sputtering; Indium nitride; Transmission electron microscopy

1. Introduction

In recent years, interest in the material InN has been remarkable. However there are relatively few reports on the piezoelectric properties of the group III nitrides and only two to our knowledge on InN [1,2]. Reports on measurements of the piezoelectric coefficients of InN are surprisingly scarce, and in part, this is due to the difficulties encountered in obtaining suitable samples. The reported d_{33} piezoelectric coefficient was obtained from a very thin InN film (193 nm thick) grown by magnetron sputtering [1]. The second value reported was measured from thicker InN layers (5 and 8 μm) grown by remote-plasma-enhanced chemical vapor deposition [2]. Since then improvements in InN crystal quality, background carrier concentration and Hall mobility have been shown [3]. InN growth is difficult because of the low thermal dissociation and the lack of lattice-matched substrates. In the past five years, there have been significant improvements in InN film growth, and there has also been substantial interest in the material due to the controversy over the band gap and extremely high predicted maximum electron mobility. The electron mobility of InN is the highest among the group III nitrides [4]. For piezoelectric measurements on InN, the crystal quality and having a reasonable thickness of material for the measurement are critical. The often observed improvement of the crystal quality with sample thickness is presumed to be due to the reduced defect density as the film growth proceeds away from the lattice-mismatched substrate. This interpretation is consistent with observations for films grown by different techniques [5,6]. Yamaguchi et al. demonstrated that up to a thickness of 120 nm the InN layer crystalline quality always improves [7]. In the case of InN grown in its wurtzite form, piezoelectricity is one of the more interesting properties to study as this material has the highest theoretical d_{33} coefficient in the group III nitrides [8]. Knowledge of the piezoelectricity in InN will also be fundamental to understanding the electrical strain in multi-layered electronic devices based on InN [9–11].

In this paper, before presenting the piezoelectric measurements, the crucial details required for obtaining reliable piezoelectric measurements are described. They include the InN growth process by radio-frequency (RF) sputtering and InN film characterization.

The piezoelectric coefficient is measured by an inverse piezoelectric effect, which means that a known field is applied to the InN film and the resultant change in the film thickness is measured interferometrically. This method yields the piezoelectric component d_{33}. The advantage of this RF sputtering growth technique compared to molecular beam epitaxy (MBE) is that the InN film can be grown at room temperature on a

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conductive substrate such as borosilicate glass coated with metal which provides a low resistance back contact for piezoelectric measurements.

2. Experimental details

InN films were grown in a reactive ion sputtering system operating at 13.56 MHz. The system incorporates a turbomolecular pump, a throttle valve pressure controller with feedback from a Baraton gauge, an in-line gas purifier capable of reducing oxygen species down to 10 parts per billion, and a load-lock allowing the growth system and the pure In target to remain constantly under vacuum. A base pressure of 2.66×10^{-5} Pa and an N_2 gas flow of 10 sccm were used. The growth period was 2 days and all the films reported here were grown on borosilicate glass degreased, cleaned and gold coated (200 nm thick) prior to loading in the growth system. The RF sputtering power was kept at 40 W and the deposition pressure was 2.13 Pa. For InN prepared by the RF reactive sputtering technique it has been demonstrated that there is a small window of growth where the InN will be grown at its best quality and stoichiometry depending on the appropriate conditioning of the In target [12,13]. If a set of samples is grown when using a fresh target with exactly the same growth parameters, the first samples are indium rich. As growth continues the target becomes nitridated [14,15]. After about 100 h of growth the target is optimally conditioned, best quality InN samples should be then obtained. Beyond this point, the target is over-nitridated and InN material is then nitrogen rich and degenerate. The drawback of this growth method is reaching the right conditioning of the target. This aspect of the growth means that only one or two good samples are grown in a set of sequential growths.

The film thickness was measured by an Apha-step Tencor surface profiler. A Cary UV–Vis double beam transmission spectrophotometer was used to collect optical transmission spectra for the band-gap measurements. The electrical resistivity, the carrier concentration, and the Hall mobility were measured by the van der Pauw method using Au contacts on the corners of 0.4 by 0.4 cm^2 samples. The structural and morphological properties were investigated using X-ray diffraction (XRD) with a Philips PW1830 diffractometer, and bright-field Philips CM 300 transmission electron microscopy (TEM). Elastic recoil detection (ERD) analysis was performed at the Australian national institute to study chemical impurities of the InN. Room temperature photoluminescences (PL) was performed on the sample using the 1064 nm line of a Nd:YAG laser as the excitation.

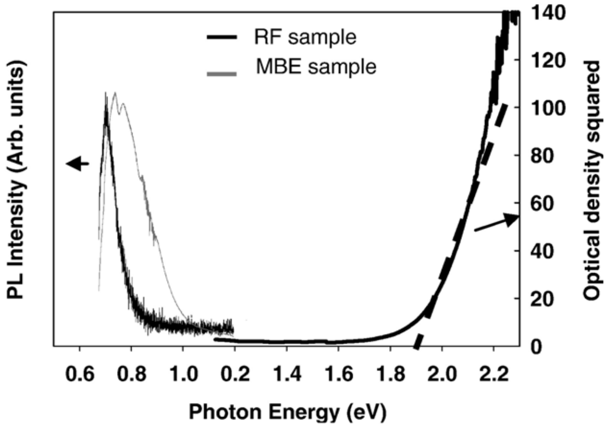

Fig. 1. Absorption coefficient squared plot for RF sputtered InN sample (extrapolation of the linear part of the spectra on the x scale indicates a band-edge at 1.92 eV) and room temperature photoluminescence spectra for an MBE sample and for the RF sputtered InN. The spectral intensities have been normalised for comparison (the intensity for the RF sputtered sample being much less). Both spectra are clipped at the lower energy side due to the response of the Ge detector used.

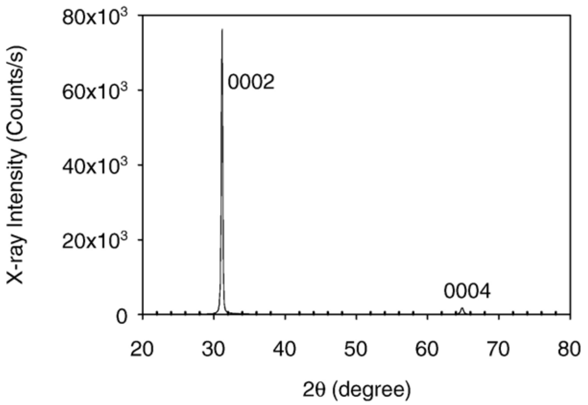

Fig. 2. XRD pattern of the InN film grown on borosilicate glass coated with gold.

The piezoelectric coefficient was measured by a laser-based interferometer.

3. Results and discussion

In a set of consecutive growths, the effect of the target nitridation has to be taken into account. The sample used in this study for the piezoelectric coefficient was taken from a growth set after more than 100 h total growth, where best stoichiometry and crystal quality are usually reached and expected. Only one or two samples would reach the best stoichiometry in a set of consecutive growths.

In a consecutive growth set the choice of the optimized sample is determined by XRD measurements indicating only sharp (0002) and (0004) wurtzite reflections, and by best mobility and carrier concentration for the growth series. Beyond proper conditioning of the In target, the samples presented a carrier concentration greater than 1×10^{20} cm^{-3} and are highly degenerate. For the InN sample analysed here the thickness measured using a Tencor profilometer was 1.7 μm. The band-edge from optical absorption squared analysis was at 1.92 eV as seen on Fig. 1. within the PL spectra. This sample was the only one in the set of consecutive samples to present a very weak PL signal at 0.77 eV. An InN sample grown by MBE is also reported in the PL spectra for comparison. The MBE sample was a 0.5 μm thick InN layer grown on a 0.2 μm GaN buffer layer on sapphire substrate. The RF sputtered sample had a carrier concentration of 3.4×10^{19} cm^{-3} for a mobility of