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Characterization of Acoustical Properties for GaN Single Crystal by the Ultrasonic Microspectroscopy Technology
超音波マイクロスペクトロスコピー技術による GaN 単結晶の音響特性評価

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1. Introduction

GaN, one of the wide bandgap semiconductor materials, is widely used as a material for blue light emitting devices. However, it is difficult to grow large bulk single crystal, so sapphire substrates are frequently used as substrates for growth of epitaxial film, resulting in problems such as lattice mismatch and residual strain. To realize high performance devices, growing and supplying the bulk substrates for homoepitaxial growth are urgent matters and establishing a technology for evaluating such substrates is also indispensable.

We have studied development and application of the ultrasonic microspectroscopy (UMS) technology in which the line-focus-beam (LFB) / plane-wave (PW) ultrasonic material characterization (UMC) system [1-3] plays central role. We are now investigating evaluation method of GaN single crystal by approaching from accurate measurements of acoustical properties. In this paper, we measured basic acoustical properties of GaN single crystal grown by the hydride vapor phase epitaxy (HVPE) [4], then tried to determine its acoustical physical constants.

2. Specimen

We prepared three specimens of (001) (*Z*-cut), (100) (*Y*-cut), and (103) (58.03°*Y*-cut) GaN single crystal substrates grown by the HVPE [4] （Mitsubishi Chemical Co.). These specimens had a typical weight of 1.4 to 2.2 g and a typical thickness of 3 mm. The top and bottom surfaces of each specimen were optically polished with a parallelism of less than 0.01°. The values of the full-widths at half-maximum (FWHM) of rocking curves for each specimen (X-ray source: CuKα_1, Ge(220) four-crystal monochromator) were 0.0218° for (006), 0.0079° for (300), and 0.0140° for (103).

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3. Experiments

3-1. LSAW velocity

Using the LFB-UMC system[1, 2], leaky surface acoustic wave (LSAW) velocities for each specimen were measured at 225 MHz. Measurement reproducibility of LSAW velocity was $\pm 2\sigma = \pm 0.05$ m/s (σ: standard deviation).

Results of the angular dependences of LSAW velocities measured for each specimen reflected the crystal symmetry and exhibited about 100 m/s lower values comparing with the calculated ones using the constants in ref. [5]. Two-dimensional distributions of LSAW velocity measured for each specimen were relatively small within 1 m/s.

3-2. Bulk wave velocity

For the above specimens, we measured velocities of longitudinal waves at frequencies from 50 to 450 MHz and of shear waves at frequencies from 40 to 200 MHz at 23°C using the PW-UMC system[3]. The results were shown in **Table I** together with the calculated ones [5]. We did not observe any velocity dispersion for either specimen in the measurement frequency range. In Table I, the measured bulk wave velocities were lower than the calculated ones for all the propagation directions.

3-3. Density

Density was measured at 23°C based on the Archimedes method [7] using the above three GaN specimens, resulting in 6087.5 kg/m^3.

4. Discussion

We determined elastic constants and piezoelectric constants using the measured bulk wave velocities in Table I (three longitudinal velocities and four shear velocities) and 58.03°*Y*-cut 90°*X*-propagating LSAW velocity, according to the constant determination procedures described in ref. [6]. The results were shown in **Table II**. In this work, we used dielectric constants of $\varepsilon^T_{11}/\varepsilon_0 = 9.5$、 $\varepsilon^T_{33}/\varepsilon_0 = 10.4$ published in ref. [8]. In

Table I Comparison of measured and calculated values of bulk wave velocities for GaN crystal.

Mode	Propagation	Pol.	Velocity [m/s]		Difference
			Measured	Calculated[5]	[m/s]
Longitudinal	*Z*	-	8038.1	8092	-53.9
	Y	-	7700.0	7963	-263.0
	58°Y	-	7604.4	7715	-110.6
Shear	*Z*	-	4018.9	4132	-113.1
	Y	*X*	4344.8	4463	-118.2
	Y	*Z*	4018.2	4158	-139.8
	58°Y	*90°X*	4630.3	4726	-95.7

Table II Comparison of determined and published acoustical physical constants for GaN crystal.

Constant		Determined	Published [5]	Diff. (%)
Elastic	c_{11}^E	3.6092	3.90	-7.5
constant	c_{12}^E	1.3109	1.45	-9.6
($\times 10^{11}$ N/m^2)	c_{13}^E	0.9538	1.06	-10.0
	c_{33}^E	3.9208	3.98	-1.5
	c_{44}^E	0.9832	1.05	-6.4
Piezoelectric	e_{15}	-0.051	-0.33	-84.4
constant	e_{31}	-0.300	-0.33	-9.1
(C/m^2)	e_{33}	0.334	0.65	-48.6
Density (kg/m^3)	ρ	6087.5	6150	-1.0

Table II, determined constants tended to be lower than those in ref. [5]. This was considered to be caused by some dislocations and impurities (Si) from the quarts reactor tube during HVPE growth[4]. The LSAW velocities calculated from the determined constants were in good agreement with the measured velocities within -0.4 to +2.5 m/s in the propagation directions which were not used in the determination procedure.

5. Summary

We measured basic acoustical properties for bulk GaN crystal grown by HVPE method using the UMS technology and determined its acoustical physical constants. Measured velocities of LSAW, longitudinal wave, and shear wave were lower than the published ones by 100 m/s order. This might be suggested some differences in crystal quality. Acoustical physical constants were determined from measured velocities. As a result, we obtained constants with accuracy within -0.4 to +2.5 m/s in LSAW velocity.

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