Piezoelectric Coefficients of Gallium Arsenide, Gallium Nitride and Aluminium Nitride

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Declaration

This thesis is submitted in accordance with the regulations for the degree of Doctor of Philosophy of Macquarie University. It reports the work carried out within the Semiconductor Science and Technology Laboratories Of Macquarie University's School of Mathematics, Physics, Computing and Electronics between July 1995 and August 1998. I declare that to the best of my knowledge the research work described herein is original, except where otherwise indicated and acknowledged. I further declare that this thesis has not, either in whole or in part, been submitted for a higher degree to any other University.

S Muensit

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September, 1998.

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Abstract

The present work represents the first use of the interferometric technique for determining the magnitude and sign of the piezoelectric coefficients of III-V compound semiconductors, in particular gallium arsenide (GaAs), gallium nitride (GaN), and aluminium nitride (AlN). The interferometer arrangement used in the present work was a Michelson interferometer, with the capability of achieving a resolution of 10^{-13} m.

The samples used were of two types. The first were commercial wafers, with single crystal orientation. Both GaAs and GaN were obtained in this form. The second type of sample was polycrystalline thin films, grown in the semiconductor research laboratories at Macquarie University. GaN and AlN samples of this type were obtained.

The d_{14} coefficient of GaAs was measured by first measuring the d_{33} value of a [111] oriented sample. This was then transformed to give the d_{14} coefficient of the usual [001] oriented crystal. The value obtained for d_{14} was (-2.7±0.1) pmV^{-1}. This compares well with the most recent reported measurements of -2.69 pmV^{-1}. The significance of the measurement is that this represents the first time this coefficient has been measured using the inverse piezoelectric effect.

For AlN and GaN samples, the present work also represents the first time their piezoelectric coefficients have been measured by interferometry. For GaN, this work presents the first reported measurements of the piezoelectric coefficients, and some of these results have recently been published by the (Muensit and Guy, 1998). The d_{33} and d_{31} coefficients for GaN were found to be (3.4 ± 0.1) pmV^{-1} and (−1.7 ± 0.1) pmV^{-1} respectively. Since these values were

measured on a single crystal wafer and have been corrected for substrate clamping, the values should be a good measure of the true piezoelectric coefficients for bulk GaN.

For AlN, the d_{33} and d_{31} coefficients were found to be (5.1 ± 0.2) pmV^{-1}, and (−2.6 ± 0.1) pmV^{-1} respectively. Since these figures are measured on a polycrystalline sample it is quite probable that the values for bulk AlN would be somewhat higher.

The piezoelectric measurements indicate that the positive c axis in the nitride films points away from the substrate. The piezoelectric measurements provide a simple means for identifying the positive c axis direction.

The interferometric technique has also been used to measure the shear piezoelectric coefficient d_{15} for AlN and GaN. This work represents the first application of this technique to measure this particular coefficient. The d_{15} coefficients for AlN and GaN were found to be (−3.6 ± 0.1) pmV^{-1} and (−3.1 ± 0.1) pmV^{-1} respectively. The value for AlN agrees reasonably well with the only reported value available in the literature of -4.08 pmV^{-1}. The value of this coefficient for GaN has not previously been measured.

Some initial investigations into the phenomenon of electrostriction in the compound semiconductors were also performed. It appears that these materials have both a piezoelectric response and a significant electrostrictive response. For the polycrystalline GaN and AlN, the values of the M_{33} coefficients are of the order of 10^{-18} m^{2}V^{-2}. The commercial single crystal GaN and GaAs wafers display an asymmetric response which cannot be explained.

List of Symbols

A	area
C	capacitance
c	specific heat, elastic stiffness
D	electric displacement
d	piezoelectric strain coefficient
g	piezoelectric strain coefficient
E	electric field
e	piezoelectric stress coefficient
h	piezoelectric stress coefficient
F	force
f	frequency
h	Planck constant
I	light intensity
i	current
k	Boltzmann constant, oscillator constant
l	length
M	electrostrictive coefficient
m	mass, electrostrictive coefficient
P	electric polarization
Q	electrostrictive coefficient
q	electron charge, electrostrictive coefficient
R	resistance
S	strain

s	elastic compliance
T	stress, temperature
t	thickness, time
V	voltage
X, x	mechanical displacement
Ω	ohm
α	coefficient of thermal expansion
β	impermittivity, shear angle
χ	dielectric stiffness
ε	dielectric constant (relative permittivity)
ε_o	permittivity of free space
η	dielectric susceptibility
λ	wavelength
ρ	resistivity
ρ_m	density
ω	angular frequency