The Basal Crystal Field in Mg-Doped GaN Studied by Frequency-Dependent EPR

Sunay, U.R., Zvanut, M.E. (U. Alabama Birmingham, Physics); Marbey, J. and Hill, S. (NHMFL and FSU, Physics); Leach, J.H. (Kyma, Inc.)

Introduction

Mg doping of GaN creates p-type material which has enabled the lighting revolution of the 21st century. Although a great deal of experimental and theoretical work has explored the many properties of the dopant, the important information gleaned from magnetic resonance is lacking due to the broad, featureless EPR signal typically obtained. Here we employ frequency-dependent EPR to demonstrate that the linewidth is largely due to non-uniform basal strain and, consequently, the hole must be located along one of the basal nitrogen atoms adjacent to the Mg impurity.

Experimental

2×2×3 mm^3 crystals of Mg-doped GaN were measured at 3.0 K in the frequency range from 37 to 130 GHz using the broadband MVNA spectrometer in the EMR facility. Phase-amplitude mixing was minimal, but nevertheless corrected for in post processing data analysis. Angle-dependent spectra were recorded in both transmission and absorption mode.

Results and Discussion

Fig.1(a) shows EPR transmission spectra thought to represent substitutional Mg in free-standing GaN:Mg. The GaN *c*-axis is oriented at 5° (black) and 40° (blue) from the static magnetic field, ***B***, at selected frequencies. The spectra shift horizontally with frequency, as expected. The increase of the linewidth with frequency, seen by a comparison of the spectra measured at about 50 GHz (lower trace) with those measured around 100 GHz (upper trace), provides evidence of *g*-strain. Furthermore, the increase in linewidth at 5° compared to that at 40° reflects the greater sensitivity to non-axial strain expected for $g_{\perp}$ compared with $g_{//}$. The detailed frequency dependence of the linewidth is shown in **Fig.1**(b). At 5°, the linewidth is almost frequency independent, indicating a very small $\Delta g_{//}$. At larger angles, the frequency-dependent linewidth is linear and increases as the angle between the *c*-axis and ***B*** increases, demonstrating the existence of a non-zero $\Delta g_{\perp}$. The frequency dependence of the linewidth shown in **Fig.1**(b), as well as the variation exhibited at different angles, verifies the assumption of *g*-strain suggested by others, and provides evidence for the appropriateness of the crystal-field model suggested by Aliev and coworkers [1,2].

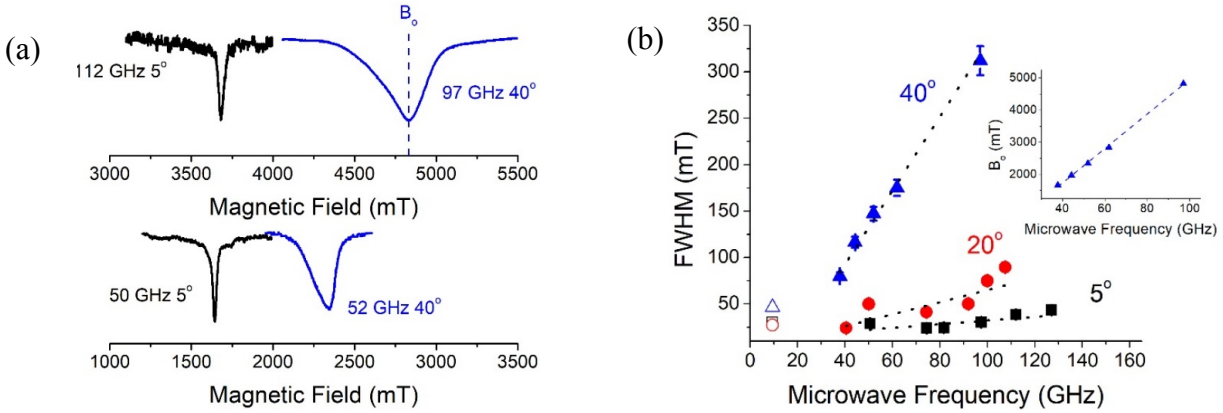

Fig.1. (a) EPR transmission spectra at 5° and 40° at two microwave frequencies. (b) Frequency dependence of the FWHM of the EPR absorptions obtained from free-standing GaN:Mg measured with the angle between the *c*-axis and ***B***: 5° (black squares); 20° (red circles); and 40° (blue triangles). Dashed lines are linear fits for each respective angle. Unfilled symbols are X-band (9 GHz) results obtained at the angle represented by the equivalent colored filled symbol. The inset shows the peak magnetic field at resonance $\boldsymbol{B}_o$ as a function of microwave frequency at 40°.

Conclusions

This work provides experimental evidence supporting the claim that the Mg acceptor in GaN is well described in both heteroepitaxial films and free-standing samples with the model of a hole on a basal site around the Mg acceptor.

Acknowledgements

The NHMFL is supported by the National Science Foundation (DMR-1157490/1644779) and the State of Florida. Work at UAB was supported by the National Science Foundation (DMR-1606765).

References

1. Zvanut, M.E., *et al.*, J. Appl. Phys., **120**, 135702 (2016).
2. Glaser, E.R., Physica B: Condens. Matter, **401-402**, 327 (2007).