# Beryllium Acceptor States in Aluminum Nitride by Cathodoluminescence Analysis

Yingying Lin [1], Jia Wang[2], Wentao Cai[3], Haitao Wang[3], Maki Kushimoto[4], Yoshio Honda[3], Hiroshi Amano[2,3]
[1]Deep Tech Serial Innovation Center, Nagoya University, Nagoya, Japan
[2]Institute for Advanced Research, Nagoya University, Nagoya, Japan
[3]Institute of Materials and Systems for Sustainability, Nagoya University, Nagoya, Japan
[4]Department of Electronics, Nagoya University, Nagoya, Japan
lin.yinging.u9@f.mail.nagoya-u.ac.jp

## Introduction

Acceptor states in AlN have attracted significant interest due to their critical role in the modulation of p-type conductivity. Recently, Ishii et al.[1] reexamined the Mg acceptor binding energy in AlN using photoluminescence (PL) measurements, revealing a significant shallower energy than previously theorized. Be, another potential acceptor when substituting Al sites, has received limited attention, with few experimental data available on its acceptor binding energy in AlN.

## Experimental Procedures

In this study, Be-doped AlN was prepared by implanting Be ions into unintentionally doped AlN epitaxial layers via metalorganic vapor phase epitaxy (MOVPE) on sapphire substrates, followed by rapid thermal annealing at 1300 °C for 20 minutes. Secondary ion mass spectrometry (SIMS) analysis confirmed a bulk Be concentration of ~$10^{19}$ $cm^{-3}$. Temperature-dependent cathodoluminescence (CL) spectroscopy was primarily employed to probe the optical properties of the doped material. X-ray diffraction (XRD) was used to measure the lattice parameters and strain values.

## Results and Discussion

A sharp emission at 6.077 eV is attributed to the neutral Be-bound exciton ($Be^0X$), with a corresponding binding energy of 44 meV. Two additional lower-energy peaks are identified as the first and second longitudinal optical phonon replicas of the $Be^0X$ transition. A +26 meV blue shift of the free exciton transition was observed relative to literature values, and XRD analysis confirmed that the AlN/sapphire heterostructure is under biaxial compressive strain ($\varepsilon_a$=−0.370%), which is consistent with reports that compressive stress increases the bandgap and in reasonable agreement with stress-based energy shift calculations. Temperature-dependent CL measurements reveal thermal quenching of the $Be^0X$ emission, with activation energies of 8.8 meV and 67 meV, corresponding to exciton delocalization and ionization, respectively. This work demonstrates, for the first time, the feasibility of Be incorporation by ion implantation and provides direct optical evidence of Be-related acceptor states in AlN, providing valuable insight into p-type doping strategies for ultrawide-bandgap semiconductors.

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## References

[1] Ishii, R., Yoshikawa, A., Funato, M., & Kawakami, Y. (2023). Revisiting the substitutional Mg acceptor binding energy of AlN. *Physical Review B*, *108*(3), 035205.

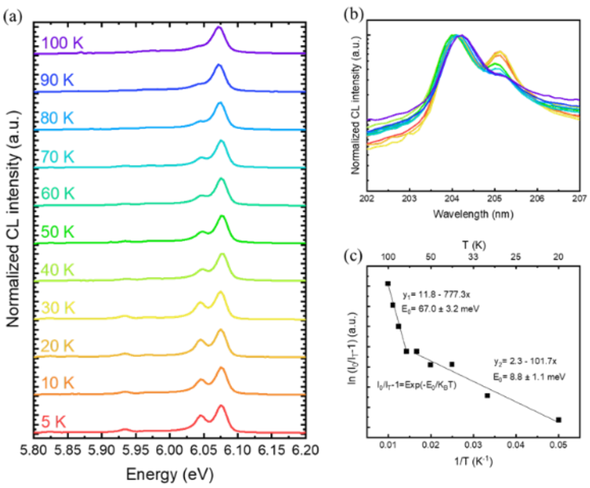


Figure 1 (a) Temperature-dependent CL spectra of Be-doped AlN from 5 K to 100 K. (b) Magnified view of the CL spectra. (c) Arrhenius analysis of the Be0X integrated intensity,