

Induced magnetic moment of Eu^{3+} ions in GaN

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1. Introduction

Magnetic semiconductors with coupled magnetic and electronic properties are of high technological and fundamental importance. Rare-earth elements can be used to introduce magnetic moments associated with the uncompensated spin of $4f$ -electrons into the semiconductor hosts [1]. The luminescence produced by rare-earth doped semiconductors also attracts considerable interest due to the possibility of electrical excitation of characteristic sharp emission lines from intra $4f$ -shell transitions. Recently, electroluminescence of Eu-doped GaN in current-injection mode was demonstrated in p-n junction diode structures grown by organometallic vapour phase epitaxy [2]. Unlike most other trivalent rare-earth ions, Eu^{3+} ions possess no magnetic moment in the ground state. Here we report the detection of an induced magnetic moment of Eu^{3+} ions in GaN which is associated with the ${}^7\text{F}_2$ final state of ${}^5\text{D}_0 \rightarrow {}^7\text{F}_2$ optical transitions emitting at 622 nm.

2. Experimental Approach and Results

We used X-ray magnetic circular dichroism (XMCD), which is the difference between the X-ray absorption spectra (XAS) for left- and right-circularly polarized X-rays. XMCD probes the magnetic moments of the states involved in the element-specific X-ray absorption process utilizing the helicity of the circularly polarized photons parallel and antiparallel to the sample magnetization direction. To measure the induced magnetic moment of Eu^{3+} ions, the bright red Eu-related luminescence (with photon energy ~ 2 eV) emitted following X-ray excitation, referred to as X-ray excited optical luminescence (XEOL), was monitored with the X-ray energy scanned across the Eu M4 (~ 1158 eV) and M5 (~ 1128 eV) absorption edges ($3d_{3/2,5/2} \rightarrow 4f$ transitions). Conventional XMCD measurements were also taken, by detecting secondary X-ray fluorescence (XRF) and the drain current caused by Auger and secondary electrons, commonly referred to as total electron yield (TEY) detection.

The XMCD feature corresponding to the M_5 absorption peak due to the $3d_{5/2} \rightarrow 4f$ transition appears at 1128.3 eV and 1129.8 eV in TEY and XEOL, respectively. When the magnetic field is reversed the XMCD features in both TEY and XEOL reverse in sign at the same energy positions as expected, thereby confirming the reliability of the observation. Note that the difference in energy of the XMCD peaks for TEY and XEOL is 1.5 eV.

The experimentally observed difference in the XMCD peak positions for TEY and XEOL can be explained by taking into account the depth sensitivity and underlying physics of each detection method. TEY is a surface sensitive, where the signal probes the sample surface with an attenuation length of ~ 5 nm. X-ray photoelectron spectroscopy indicates that Eu^{3+}

undergoes a valence-state transition into Eu^{2+} near the surface of GaN [3]. Therefore, the XMCD measured by TEY clearly indicates the presence of Eu^{2+} ions at the surface of GaN. On the other hand, visible photons emitted by Eu^{3+} are collected from the entire depth of the epilayer. Since the visible luminescence of the sample is dominated by the emission line at 622 nm due to ${}^5\text{D}_0 \rightarrow {}^7\text{F}_2$ intra- $4f$ shell transitions with a magnetic final state, the XMCD spectrum measured by XEOL detection uniquely probes the induced magnetic moment of the excited ${}^7\text{F}_2$ state of Eu^{3+} ions in the bulk of the epilayer.

3. Conclusions

In summary, we report the detection of an induced magnetic moment of Eu^{3+} ions in the ${}^7\text{F}_2$ state, which is associated with the ${}^5\text{D}_0 \rightarrow {}^7\text{F}_2$ intra- $4f$ shell optical emission line at 622 nm. The unique features of Eu^{3+} ions are the non-magnetic ${}^7\text{F}_0$ ground state and magnetic ${}^7\text{F}_{1,2,3}$ states, which can be populated optically or electrically in an LED structure. Another unique property of Eu^{3+} is its non-magnetic ${}^5\text{D}_0$ excited state. Apart from inducing a magnetic moment by forcing the Eu^{3+} ion to emit a photon, one can switch off the induced magnetic moment by shining light with an energy specific to the transitions from the ${}^7\text{F}_j$ manifold to the ${}^5\text{D}_0$ state to which GaN is transparent. This opens up a very interesting perspective for electrical or optical manipulations with the excited-state magnetic moments of Eu^{3+} in GaN.

4. Open Questions

- Is it possible to have ferromagnetic interaction between excited Eu^{3+} ions?
- How magnetic properties depend on the nature of Eu^{3+} centers in GaN?
- Is induced magnetic moment of Eu^{3+} related to room-temperature ferromagnetism observed in Eu-doped GaN?

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References

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