Cu-doped AlN: A possible spinaligner at room-temperature grown by molecular beam epitaxy?

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Abstract. Cu-doped AlN was prepared by plasma assisted molecular beam epitaxy on *C*-plane sapphire substrates. The growth conditions were investigated for different Cu to Al flux ratios from 1.0% to 4.0%. The formation of Cu-Al alloys on the surface was observed for all doping level. In contrast to Cu-doped GaN, all samples showed diamagnetic behavior determined by SQUID measurements.

Keywords: diluted magnetic semiconductors, group-III nitrides, spinalingement, molecular beam epitaxy
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INTRODUCTION

Group-III nitride semiconductors cover a large bandgap-area and have good thermal and chemical stability. They are therefore interesting for many optoelectronic applications and devices. In particular, nitride-based spintronic is an emerging field of interest. One reason for this strong interest is the long, temperature independent spin-lifetime in InN quantum dots.[1, 2] Therefore, nitride-based spintronics could be an interesting alternative to arsenide-based spintronics.

A prerequisite for spin-injection is a ferromagnetic layer with a Curie temperature far above room-temperature and a high spin-polarization. Diluted magnetic semiconductors (DMS) are the most promising candidates for a ferromagnetic layer. DMS exhibit ferromagnetism by substituting a small amount of group-III elements by transition metals. The most common materials for doping are intrinsic magnetic materials like manganese (Mn) or gadolinium (Gd). AlN doped with these elements exhibit ferromagnetic behavior above room-temperature, which was shown by theoretical calculations[3] as well as experiments.[4, 5] However, experimental results show the formation of secondary phases in the group-III nitride host[6, 7], which influence the magnetic properties of the DMS. Therefore, the origin of the ferromagnetic behavior is unclear.

To overcome the problem with magnetic secondary phases, non-magnetic dopands are required. These dopands should also have a not completely filled 3d shell, when it is implanted in the AlN host. This requirement is important for the magnetic properties, because the 3d electrons are strongly involved in the mechanisms, which are found to be the origin of the ferromagnetic behavior.[8] A promising candidate that fulfills all requirements is Copper.

Theoretical calculations suggest for Cu-doped AlN[9, 10] a 100% spin polarization and a Curie-temperature far above room-temperature. Also a high magnetic moment of 2.0 μ_B per Cu-atom is predicted. First experimental results for Cu-implanted AlN[11] showed room-temperature ferromagnetism. It was found that the magnetic moment decreases with increasing the amount of Cu, while the magnetic properties are very sensitive to annealing procedures. Ferromagnetism was also found in Cu-doped AlN nanorods[12] grown by chemical vapor deposition. Secondary phases are also found in Cu-doped AlN[13]. These phases are in contrast non magnetic and have therefore no influence on the magnetic properties. Also defects can play an important role on the magnetic properties[11]. Therefore a technique for growing high quality films with only few defects like molecular beam epitaxy is required the exclude such effects.

METHODS

Cu-doped AlN was grown by plasma-assisted molecular beam epitaxy on *C*-plane sapphire substrates. The substrates were glued on silicon wafers with indium for a better and homogenous heat transfer during growth. A prior nitridation of the sapphire

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surface was performed at 200°C in an activated nitrogen atmosphere. After nitridation, Cu-doped AlN was grown for 2 hours at a substrate temperature of 850°C. During growth, reflection high-energy electron diffraction (RHEED) indicated the surface morphology.

After growth, scanning electron microscopy (SEM) provided information about the surface morphology. Superconducting quantum interference device (SQUID) measurements yielded information on the magnetic properties of Cu-Doped AlN.

RESULTS AND CONCLUSION

Figure 1 shows a typical SEM image of the surface of Cu-doped AlN. The surface is covered by islands of different sizes. The island form is a mixture of sharp cubic and hexagonal shape.

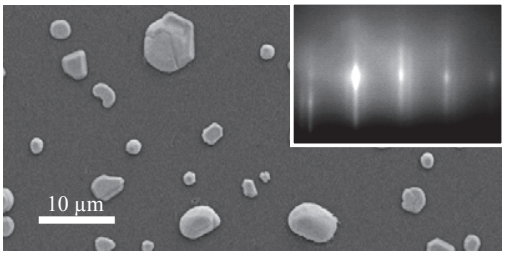

FIGURE 1: SEM image of the Cu-doped AlN surface, with a nominal doping of 1.2%. The inset shows a streaky RHEED pattern.

It was found by Energy-dispersive x-ray spectroscopy (EDS) that the islands consist of about 60% Cu and 40% Al. Hence, the islands are inter-metallic compounds and will not influence the magnetic properties. Next to the islands, a weak Cu signal was detected. This leads to the conclusion that the incorporation of Cu into the AlN host is not favorable, but a small amount of Cu gets still incorporated which would be necessary for ferromagnetic behavior. The surface next to these islands is flat, which was also observed during growth by RHEED (inset Fig.1).

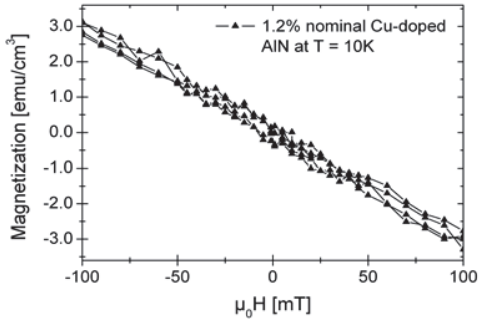

FIGURE 2: Magnetization versus magnetic field for the 1.2% nominal Cu-doped AlN measured by SQUID.

The magnetization curve in Fig. 2 shows a clear diamagnetic behavior at low temperature for the 1.2% nominal doped Cu-doped AlN. Also for other nominal Cu doping levels no ferromagnetic behavior was found. A reason for the absence of ferromagnetism can be explained by the low Cu concentration in the film.

In conclusion, we epitaxial grew flat Cu-doped AlN films with different nominal Cu-doping level from 1.0% to 4.0%. The formation of islands on top of the surface was observed for all doping level. A ferromagnetic behavior was not observed from SQUID measurements.

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