Cu-doped nitrides: promising candidates for a nitride based spinaligner

P. R. Ganz[1,2,*], G. Fischer[3], C. Sürgers[1,3], and D. M. Schaadt[1,2]

[1]*DFG-Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany*
[2]*Institut für Angewandte Physik, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany*
[3]*Physikalisches Institut, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany*

Nitride based spintronics is emerging as an interesting alternative to arsenide based spintronics. The strong interest for using group-III nitrides in spintronics is motivated by a long and temperature independent spin-lifetime in InN quantum dots [1, 2]. In addition, group-III nitride semiconductors cover a large bandgap-area and have good thermal and chemical stability and are therefore interesting for all optoelectronic devices. For spin-injection a ferromagnetic spin-aligner which yields high spin-polarization at room-temperature is the crucial point. The most promising candidates for such a ferromagnetic layer are diluted magnetic semiconductors (DMS). DMS are conventional semiconductors doped with a small amount of transition metals. Most used dopants are intrinsic magnetic materials like Manganese or Gadolinium. However, confusing results were reported for Mn- and Gd-doped nitrides [3, 4]. In these cases, ferromagnetism could also be caused by magnetic clusters in the nitrides host which was showed experimentally [5, 6]. By using non-magnetic dopants, problems with magnetic clusters were avoided. Copper as a non-magnetic transition metal is a promising candidate.

First density functional theory (DFT) calculations for Cu-doped nitrides in 2006 by Wu et al. [9] suggested a 100 % spin-polarization of the conduction carriers and a Curie-temperature above 350 K. Also a high total magnetization of 2.0 μ_{Bohr} per Cu atom was calculated. In contrast, DFT calculations by Rosa and Ahuja [10] showed only a weak ferromagnetism, making the material unsuitable for spintronic applications. Experimental results were reported for Cu-doped nitrides nanowires [14, 15], Cu-implanted GaN [11, 12, 13] and CVD grown Cu-doped GaN [16]. All results show room-temperature ferromagnetism. For Cu-implanted samples, annealing is necessary to obtain ferromagnetism. The ferromagnetic properties were sensitive to Cu doping levels and the used methods.

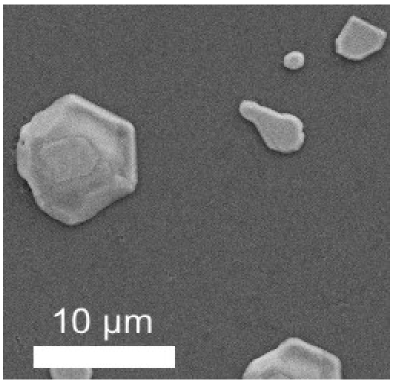

Fig. 1: Cu-doped GaN with Cu-Ga islands on top of the surface

We investigated and optimized the growth of Cu-doped nitrides by plasma assisted MBE on *C*-plane sapphire substrates. The influences of growth parameters such as growth temperature, Cu to metal beam equivalent pressure (BEP) ratio and metal to nitrogen BEP ratio on the structural and magnetic properties were analyzed.

All samples were grown nearby the stoichiometric composition to obtain flat films as determined during growth by reflection of high-energy electron diffraction (RHEED) and ex-situ by scanning electron microscopy (SEM) and atomic force microscopy (AFM). The structural properties were also determined by x-ray diffraction (XRD). The Cu doping level was varied from 0.1% to 5.0% Cu to metal BEP ratio.

For both, Cu-doped GaN and Cu-doped AlN the formation of islands on top of the surfaces were observed (Fig. 1). With increasing the Cu doping, the islands were also increasing in size and amount. The composition of these islands was determined by Energy dispersive x-ray absorption spectroscopy (EDX). Only Cu and metal could be found in these islands. The magnetic properties, on which these islands will have no influence due to their metallic character, were identified by supersonducting quantum interference device (SQUID). Cu-doped GaN showed ferromagnetic behavior for all samples. The highest magnetic saturation was obtained for a sample grown by at Cu to Ga BEP ratio of 1.2%. For this sample, ferromagnetic behavior was also observed at a temperature of 400 K (Fig. 2), the maximum temperature which can be obtained in our setup.

[1] S. Nagahara, M. Arita, and Y. Arakawa, Appl. Phys. Lett. 86, 242103 (2005)
[2] S. Nagahara, M. Arita, and Y. Arakawa, Appl. Phys. Lett. 88, 083101 (2006)
[3] G. T. Thaler et al., Appl. Phys. Lett. 80 3964 (2002)
[4] S. Dhar et al., Phys. Rev. B 72 24520 (2005)
[5] J. M. Baik et al., Appl. Phys. Lett. 82 583 (2003)
[6] S. Dhar et al., Appl. Phys. Lett. 82 2077 (2003)
[9] R. Q. Wu et al., Appl. Phys. Lett. 89, 062505 (2006).
[10] A. L. Rosa and R. Ahuja, Appl. Phys. Lett. 91 232109 (2007)
[11] J. H. Lee et al., Appl. Phys. Lett. 90 032504 (2007)
[12] X. L. Yang et al., Journ. Appl. Phys. 105 053910 (2009)
[13] F. Y. Ran et al., Appl. Phys. Lett. 95 112111 (2009)
[14] H. K. Seong et al., Nano Lett. 7 (11) 3366 (2007)
[15] X. H. Ji et al., Nanotechnology 18, 105601 (2007)
[16] C. H. Choi et al., Journ. Mat. Res. 24 (5), 1716 (2009)
[17] Blaha P, Schwarz K and Sorati P 1990 Comp. Phys. Communications 59 339

* P. Ganz, e-mail: philipp.ganz@kit.edu