平成 22 年 7 月 12 日

各　位、

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第 1 回 CSIS セミナー
第 46 回ナノ・スピン工学研究会
半導体スピントロニクス研究部講演会の開催について

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さて、下記の通り講演会を開催致しますので皆様多数ご参集下さいますようご案内申し上げます。

日　時：　平成 22 年 8 月 6 日（金）16:00-17:30
場　所：　電気通信研究所　ナノ・スピン総合研究棟 4 階　A401 号室
講　師：　**Dr. M. Sawicki**, Institute of Physics, Polish Academy of Sciences, Warsaw, Poland
講演題目：**The Magnetism of x ≤ 0.03 (Ga,Mn)N**

概　要：　A number of controversial reports on the magnetic properties of (Ga,Mn)N call for a systematic study of its magnetic and structural characteristics as a function of the fabrication methods and parameters. Room temperature ferromagnetism has been recently claimed in (Ga,Mn)N/(Ga,Al)N:Mg heterostructures also for Mn concentrations well below 1% [1]. At the same time, it has been suggested that a strong *p-d* hybridization results in a deep location in the band gap of the neutral acceptor Mn^{3+} state, which precludes hole delocalization and renders the observation of hole mediated ferromagnetism difficult [2]. Nevertheless, a series of *ab initio* studies [3] suggest a possibility of ferromagnetic ordering of diluted magnetic spins caused by a ferromagnetic double exchange.

Here we focus on dilute $Ga_{1-x}Mn_xN$ layers ($x < 0.03$) grown by metalorganic vapor phase epitaxy – an essential step on the way of understanding the magnetic coupling in more concentrated layers. We carried out a comprehensive nanoscale characterization, based on high resolution transmission electron microscopy, synchrotron radiation in diffraction and absorption experiments, with the main emphasis put on SQUID magnetometry - in order to identify unambiguously the dilute nature of Mn atoms in the samples [4].

Up to about $x = 0.02$ synchrotron x-ray diffraction experiments gave no evidence of crystalline phases other than wurtzite GaN. Moreover, both low magnification and high resolution TEM confirm the homogeneity and single-phase nature of the (Ga,Mn)N. Energy dispersive x-ray spectroscopy rules out even the presence of coherent aggregation of the magnetic ions. The x-ray extended absorption fine structure spectra also confirms that the Mn atoms Mn atoms substitute Ga atoms and they are uniformly distributed.

The magnetic properties as a function of temperature, magnetic field and its orientation with respect to the c-axis of the wurtzite structure confirm the single-phase nature of the layers with $x < 0.01$. None of the ferromagnetic-like features, so typical of GaN:Fe are seen here. Importantly, the whole set of experimental data can be *quantitatively* described by the paramagnetic theory of an ensemble of non-interacting Mn^{3+} ions in a relevant crystal field [5], a conclusion consistent with the x-ray absorption near edge structure analysis. A negligible contribution of Mn in the 2+ charge state points to a low concentration of residual donors in the studied films. Layers with $x > 0.01$ exhibit a contribution of ferromagnetic Mn-Mn interaction. Its strength and dependence on the Mn charge state in GaN will be discussed. Additionally, our magnetometry on modulation doped (Ga,Mn)N/(Ga,Al)N:Mg heterostructures do not reproduce the high temperature robust ferromagnetism reported recently for this system. The work has been done with collaboration of W. Stefanowicz, D. Sztenkiel, R. Jakiela, and T. Dietl from Institute of Physics in Warsaw, and T. Devillers, A. Navarro-Quezada, B. Faina, and A. Bonanni from Linz University, Austria.

[1] N. Nepal *et al.*, *Appl. Phys. Lett.* **94**, 132505 (2009).
[2] T. Dietl, *Phys. Rev. B* **77**, 085208 (2008).
[3] see e.g.: M. Toyoda, *et al.*, *Phys.Stat. Sol. (c)* **3**, 4155 (2006).
[4] W. Stefanowicz *et al.*, *arXiv 0912.4216.*
[5] J. Gosk *et al.*, *Phys. Rev. B* **71**, 094432 (2005).

問い合わせ先：CSIS・山ノ内、大野研究室・佐藤（片平5554）