

Mn, GaMn AND MnAs ON GaN(0001)-(1×1) SURFACE

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Gallium nitride attracts much of interest mainly because of its characteristics useful for optoelectronic applications [1]. Recently, however, it has been shown that GaN doped with manganese can be a promising candidate for a ferromagnetic semiconductor with a Curie temperature higher than room temperature [2]. Thus, it would be a promising material for applications in spintronics [3-5]. Most of the reported studies were performed for samples of GaMnN prepared by molecular beam epitaxy (MBE) but annealing of Mn/GaN system under UHV conditions was also considered as a technique suitable for fabrication of this compound [3]. However, the mechanism of Mn atom introduction into GaN lattice as well as the character of species formed in the doped layer are under debate. It is known that doping of GaN crystals by deposition of an element on the surface and annealing is difficult due to low diffusion coefficients at the temperatures lower than the decomposition temperature of GaN. Probably, the diffusion observed for GaN epilayers grown on sapphire is enhanced by the presence of dislocations. So, properties of GaMnN are investigated for samples prepared by various methods and the quest for a magnetic material, suitable for fabrication of spintronic devices and compatible with semiconductors used in electronic applications, is still in progress. Ferromagnetic compounds of Mn, like GaMn and MnAs, are also considered as promising candidates [6-10]. For MnAs, coupling between its magnetic properties and structural characteristics inspired attempts to grow it on various substrates [e.g. GaAs(001), GaAs(111)].

In this paper we report studies of Mn, GaMn and MnAs layers deposited by MBE technique on GaN(0001)-(1×1) surface. The electronic structures of these systems were investigated by means of photoelectron spectroscopy (Fig. 1). In particular, the resonant photoemission was used in order to reveal a contribution of Mn 3*d* states against the background of emission from the valence band. Thus, sets of photoelectron energy distribution curves were acquired for photon energies near to Mn 3*p*→3*d* excitation. Interactions between deposited species and GaN were also monitored by spectroscopy of the Ga 3*d* core level. The photoemission experiments were carried out at the beamline 41 (MAX-I) in the synchrotron radiation laboratory MAX-lab, University of Lund, Sweden.

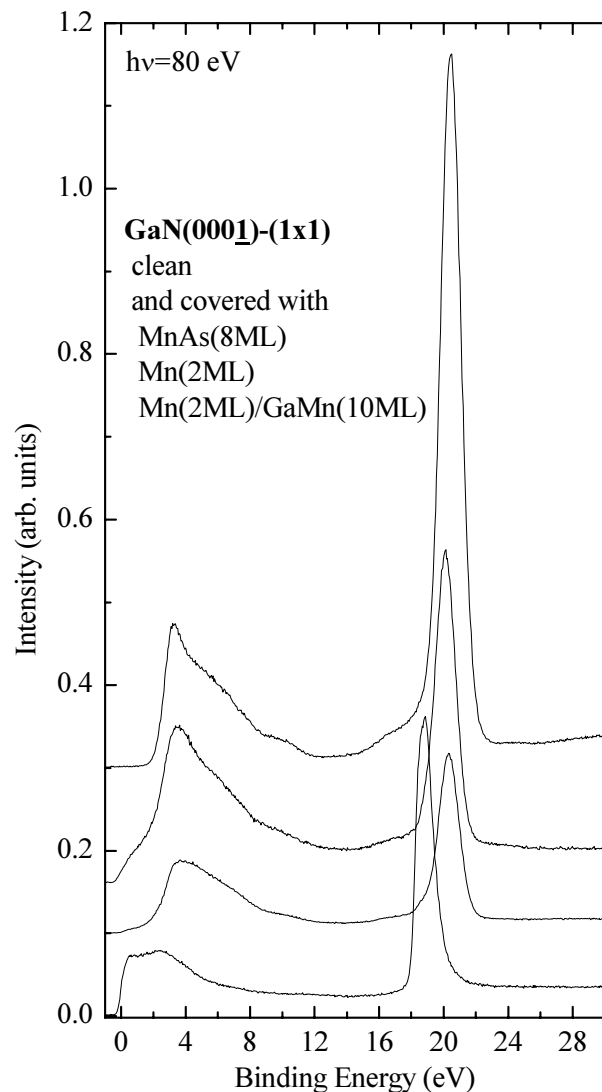


Figure 1. Photoemission spectra of the investigated systems obtained for $h\nu = 80$ eV.

The first part of the reported experiment consisted in measurements carried out for freshly cleaned, ordered GaN(0001)-(1×1) surface, after deposition of Mn (at the substrate temperature of 350°C) and after additional annealing of the system. Comparison of the curves taken at resonance and at antiresonance, for both clean and

Mn-enriched surface, enabled us to reveal the Mn 3*d*-related contribution to the spectra. It has the maximum at 4.5 eV below the Fermi level. Its shape is substantially different from that of metallic Mn. Thus, an interaction between Mn atoms and GaN surface have to be taken into account. Further annealing of the sample brought about increase of photoemission intensity (possibly due to improvement of the surface quality), without marked change in the shape of the spectra. Deposition of 10 ML of GaMn enabled us to show that the shape of the valence band as well as the energy position of the Ga 3*d* core level peak of Mn/GaN are substantially different from those observed for GaMn. This means that deposition of Mn on GaN at the temperature of 350°C leads to introduction of Mn atoms into the surface region of GaN but amount of GaMn precipitates is negligible. So, the applied technique is quite promising as a method of GaN surface doping with Mn.

Study of MnAs on GaN(0001) was motivated by the fact that both materials have hexagonal structures in the plane perpendicular to the *c* axis but $a_{\text{MnAs}} > a_{\text{GaN}}$. So, formation of MnAs dots in this system can be expected (in contrast to MnAs/GaAs(111) system [11]). Thus, the layers of MnAs were deposited stepwise and their structure was assessed by RHEED and LEED techniques. The electronic structure of the grown system was investigated *in situ* at each stage of growth (1, 2 and 8 ML) by means of photoelectron spectroscopy. The morphology of the surface formed by deposition of 8 ML of MnAs was studied *ex situ* by atomic force microscopy (AFM).

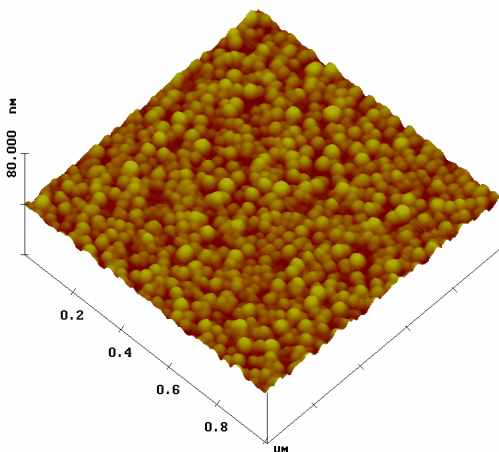


Figure 2. Surface morphology of 8 ML MnAs grown on GaN(0001)-(1×1), obtained by AFM.

The first steps of deposition (1 and 2 ML) induced some blurring of the streaked pattern of the clean GaN(0001)-(1×1) surface. During further deposition an improvement of the pattern (streaks became again

stronger and sharper) was observed then, at about 7 ML, the critical thickness of the layer was achieved and dots, characteristic of 3D growth, appeared in the RHEED pattern. An AFM investigation of the sample surface morphology confirmed that MnAs formed grains of the diameter 30-60 nm and the average height of 4 nm (Fig. 2).

The Mn 3*d* related feature resolved in the resonant photoemission spectra of MnAs was markedly different from that of pure Mn and confirmed that Mn formed a chemical compound. The As 3*d* core level peak consisted of two components, most probably corresponding to bulk and surface As atoms. Analysis of photoemission spectra of Ga 3*d* revealed no manifestation of the GaN surface disruption during MnAs deposition. Starting from 2 ML coverage a density of states at the Fermi level appeared, which indicated that the deposited layer had metallic properties. Studies of magnetic properties of the grown MnAs/GaN system are under progress.

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