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A RESONANT PHOTOEMISSION STUDY OF Co/GaN SYSTEM

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Mn-based III-V semiconductors are most intensively investigated as promising ferromagnetic materials with a high Curie temperature, possibly higher than room temperature. However, theoretical calculations suggest that other transition metals (TMs) (like Co, Fe, Cr, Ni) can also be considered as magnetic impurities possibly leading to ferromagnetism at relatively high temperatures [1]. The detailed investigations of interactions between a transition metal and semiconductor surface contribute to our knowledge about processes occurring inside semiconductors doped with TMs.

We report the resonant photoemission studies of interface formation on bulk GaN crystal surface gradually covered with Co (from 0.25 ML to 12 ML) and annealed at 500°C under ultra-high vacuum (UHV) conditions. The goal of this study was to examine the chemical interactions at the interface between Co atoms and clean GaN surface, to reveal compounds formed at the interface and to relate them to changes in the density of states distribution of the valence band of Co/GaN system.

The bulk crystals of GaN were grown in the Institute of High Pressure Physics, PAS (Warsaw, Poland). The resonant photoemission experiments were performed at the FLIPPER II beamline at the HASYLAB synchrotron radiation laboratory (Hamburg, Germany). The GaN $(000\underline{1})$-(1×1) surface was prepared *in situ* by repeated cycles of Ar^+ ion sputtering and annealing at 500ºC under UHV conditions. The surface crystallinity was assessed by low energy electron diffraction (LEED) method. The surface conditions were controlled by spectroscopy of Ga 3*d* core level.

Co was deposited stepwise from a Knundsen cell in a UHV chamber directly connected with the photoelectron spectrometer. Amount of the evaporated Co was monitored with a quartz thickness monitor.

The sets of photoelectron energy distribution curves were measured for clean GaN surface and after each stage of Co evaporation at the room temperature starting from submonolayer coverages (Figs. 1 and 2). When the thickness of Co layer reached 2 ML, the sample was annealed at 500°C. The energy scale origin was set the Fermi level (as measured for a thick Co layer). Photoemission experiments were carried out for photon energies close to Co 3*p*→3*d* transition (about 63 eV). The contribution of resonant photoemission can be described by the Fano formula [2]. Comparison of the curves taken at resonance and antiresonance for clean and Co-enriched surface enabled us to reveal the Co 3*d*-related contribution to the spectra (Figs 1 and 2). The collected spectra show the valence band of the system (from the Fermi edge to about 12 eV) and the Ga 3*d* peak (at about 20 eV).

Spectra measured in the constant-initial-state (CIS) regime clearly showed a Fano-type profile. In the case of Co/GaN system a resonant enhancement is located at the photon energy about 63 eV (corresponding to Co 3*p*-3*d* transition) and minimum at 59 eV.

Interaction of Co atoms with the GaN surface manifested itself by changes in the valence band shape, which indicated Co diffusion into the surface and subsurface region of the sample. The sharp onset of the spectra at the Fermi energy (for thick Co layer) suggests metallic properties of the layer probed in the photoemission experiment. The Ga 3*d* peak occurs at 20 eV, although its intensity is strongly reduced due to deposited Co layer. Co remaining on the surface manifests itself as an additional structure discernible in the spectra.

The annealing process enhanced reaction of Co with Ga. It resulted in the appearance of the additional peak just above the Ga 3*d* maximum (at 18.5 eV, in consistence with [3]). Simultaneously there was less metallic Co on the Fermi edge. The presence of considerable amount of CoGa was confirmed by SIMS - ToF measurements.

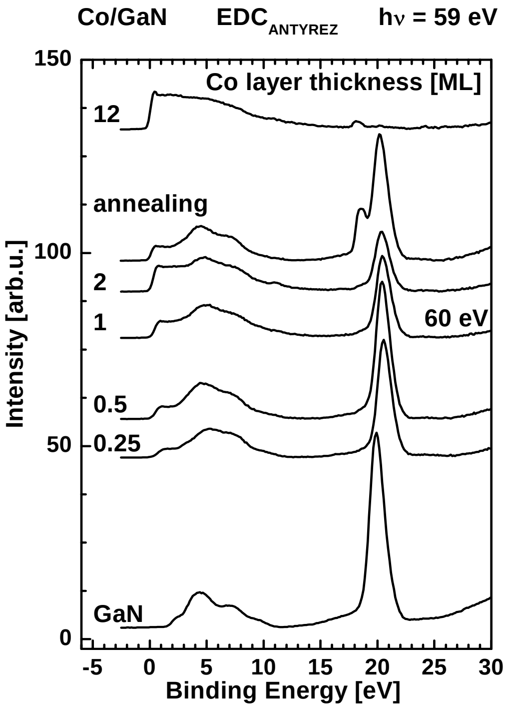

Figure 1. EDCs obtained from GaN surface covered with Co, measured for antiresonant energy.

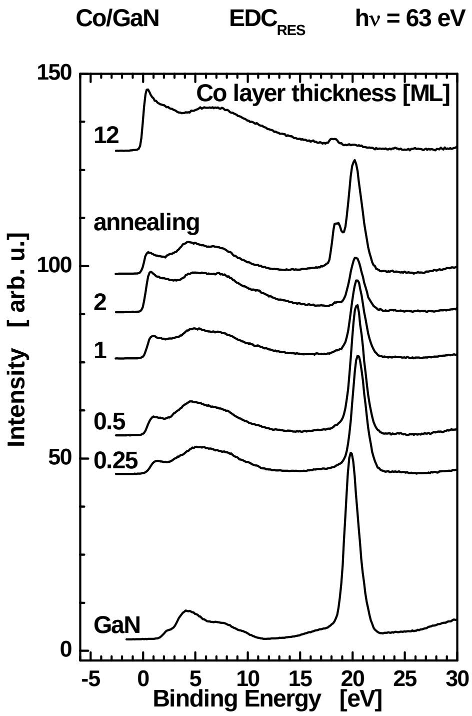

Figure 2. EDCs measured for photon energy corresponding to the 3*p*→3*d* excitation (resonance energy).

Strong interaction between Co and Ga differentiates Co/GaN interface from previously investigated Ti/GaN and Mn/GaN systems. At those interfaces TM-N interaction dominated. The annealing enhanced reaction of metallic Ti with N (the valence band became similar to that observed for titanium nitride). Annealing of the Mn/GaN system induces changes in Mn atom environment. Mn 3*d* contribution to the valence band density of states becomes similar to that characteristic of Mn built into semimagnetic semiconductors.The reported study was complemented by sample surface morphology studies performed by means of atomic force microscopy (AFM) and scanning tunneling microscopy (STM) (Fig. 3). These investigations proved that the surface formed grains of the various diameter, average 30 nm and the average height of 4 nm.

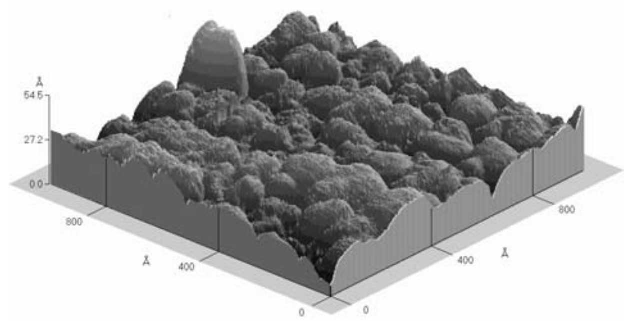

Figure 3. Surface morphology of 12 ML Co grown on GaN(000$\bar{1}$)-(1×1), obtained by STM measurement.

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