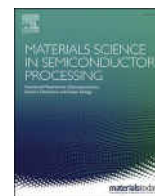




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Synthesis and properties of β -Ga₂O₃ nanowires and nanosheets on doped GaS:Mn substrates

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ABSTRACT

In this work, the synthesis, morphology, optical and luminescence properties of Mn-doped β -Ga₂O₃ (Ga₂O₃:Mn) nanowires/nanosheets on Mn-doped GaS (GaS:Mn) substrate are studied. The aim was to obtain structures of semiconductors with layers of nanoformations (nanowires, nanosheets) from a wide energy band semiconductor such as β -Ga₂O₃ and to determine their characteristic properties. For the base material, Mn-doped GaS lamellae were chosen, which are optically transparent in the spectral region where the optical properties of Mn²⁺ and Mn³⁺ ions are manifested. Through thermal annealing, single-crystalline β -GaS plates doped with 1.3 atomic percent (at.%) of manganese (Mn) are exposed to an atmosphere enriched with H₂O vapor at a temperature of 800 °C for 6 h. As a result, the surface of these plates is covered with a composite layer consisting of crystallites of α -Ga₂S₃:Mn and β -GaS:Mn planar junctions. This composite exhibits a direct band gap of 2.88 eV and an indirect band gap of 2.55 eV corresponding to the β -GaS:Mn crystallites. Upon further increasing the temperature during thermal annealing to 850 °C and 920 °C, the surface of the β -GaS:Mn samples transform into a layer of β -Ga₂O₃:Mn nanowires/nanosheets with a band gap of 4.5 eV. Its intense green-orange photoluminescence is caused by electronic transitions within the Mn²⁺ ion.

1. Introduction

In recent years, wide bandgap semiconductors have received considerable research attention due to their unique physical properties and potential applications in various electronic devices [1]. Among these semiconductors, compounds such as GaN, Al_xGa_{1-x}N, and oxide semiconductors like TiO₂, ZnO, MgZn_{1-x}O, and Ga₂O₃ (especially monoclinic β -Ga₂O₃) have attracted particular interest due to their application in ultraviolet radiation photo-detectors (UVB and UVC), power electronic devices, and of UV radiation sources [2–5]. The range of applications of these materials is expanding with the transition from massive bulk single crystals to micro- and nano-crystallites [6,7]. Gallium oxide (β -Ga₂O₃) is a *n*-type semiconductor with a direct bandgap of about 4.4–4.9 eV and a monoclinic crystal lattice. The high-temperature stability of β -Ga₂O₃ can be achieved by doping with chemical elements

such as Zn and Sn [8,9]. As a result, it is considered a promising material for use in UV optoelectronics, acting as a photocatalyst for the decomposition of organic pollutants and water, and functioning as a sensor for toxic gases at high temperatures [10–12].

One of the basic parameters that determine the applicability of this material in electronic devices is the critical (breakdown) electric field. For undoped β -Ga₂O₃, the critical electric field is about 8 MV/cm, while for β -Ga₂O₃ doped with Zn, this parameter reaches the value of 13.2 MV/cm. In addition, β -Ga₂O₃:Zn in nanosheets exhibits intense photoluminescence in the green region [13] and shows high sensitivity as a photo-detector in the UVC region, with response reaching up to 210 A/W at a wavelength of 232 nm [14].

Nanostructured undoped and doped β -Ga₂O₃ grown on substrates such as Si, GaN, GaAs, Al₂O₃, and other oxide semiconductors such as TiO₂ and ZnO play an important role in the development of electronic

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devices, UV radiation receivers and sources, gas sensors, and photocatalysts [14–17]. It has been shown that the manganese (Mn) dopant induces impurity bands near the band edge, resulting in the decrease of the band gap of the Ga_2O_3 [18].

Considering that GaS:Mn is an optically transparent material in the region where the luminescent transitions of Mn^{2+} and Mn^{3+} ions are manifested, thus also obtaining intense luminescence in the green-orange region. A thorough knowledge of the basic structural, optical and vibrational properties of Mn-doped $\beta\text{-Ga}_2\text{O}_3/\text{GaS:Mn}$ is crucial, since information on cost-efficient and simple technological approaches and structure is still lacking. Mn - doped composites as $\beta\text{-Ga}_2\text{O}_3/\text{GaS:Mn}$ are extremely important for fundamental research, as well as for developing new devices, e.g. various applications including optoelectronic sensors, non-toxic biomedical imaging, energy down-conversion in nanostructured solar cells, nonlinear optical applications, optoelectronic devices, e.g., high-power laser radiation sensors. Recent structures demonstrate that Mn-doped $\beta\text{-Ga}_2\text{O}_3$ thin films as well as nanostructured layers are promising materials in light sources in the visible region of the spectrum under electron beam excitation and photon excitation in the UV region.

In this work, the synthesis and morphology of Mn-doped $\beta\text{-Ga}_2\text{O}_3$ ($\text{Ga}_2\text{O}_3:\text{Mn}$) nanowires/nanosheets on Mn-doped GaS (GaS:Mn) substrates are investigated. Furthermore, the composition as well as the optical and luminescence properties of Mn-doped $\beta\text{-Ga}_2\text{O}_3$ nanowires/nanosheets on a GaS:Mn substrate are investigated in detail.

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