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Investigations on the nanostructures of GaN, InN and $In_xGa_{1-x}N$

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ABSTRACT

A controllable approach to the formation of III- nitride nanocrystalline structures using hydrothermal assisted method is presented. The structural and morphological properties of the prepared nanostructures are analyzed using X-ray diffraction, Fast Fourier Transformation and transmission electron microscope techniques. The temperature dependent structural formation of nitride nanostructures have been systematically investigated using X-ray diffraction. Raman spectra of the samples grown at optimized condition exhibited different phonon modes of the respective nitrides (GaN, InN and $In_xGa_{1-x}N$). Nanoparticles and nanorods formation of the indium nitride and indium gallium nitride are observed in the TEM micrographs. FFT analysis revealed that the synthesized III-nitride nanostructures are of good crystalline quality. Nanorods of these nitrides showed better crystalline quality than the nanoparticles in the FFT reflections.

1. Introduction

The favorable optical and electronic properties of $In_xGa_{1-x}N$ alloy attract enormous interest in the optoelectronic applications. Gallium nitride being a wide band gap (3.4 eV) and Indium nitride as a narrow one (0.7 eV), their alloys cover a considerable range of emissions in the visible spectrum [1]. The continuously tunable gap over a wider range also opens up an interesting opportunity for using these alloys in high-efficiency solar cells. The compatibility of Gallium nitride alloys at high temperature, pressure and chemical environment, make them to be used for wide variety of applications such as power electronics [2], sensors [3], UV detectors [4] and spintronics [5]. Epitaxially grown GaN received great interest to be used as high-electron mobility transistors (HEMT) [6] because of its high carrier mobility, higher breakdown voltage and high speed.

Indium nitride (InN) being a smaller bandgap material, determining the exact band gap value, thermal stability and preparation in stoichiometric form is still a challenging task. Tsen et al. have observed higher electron drift velocities in InN at the order of 10^8 cm/s and it is higher than that of other nitrides of its group [7]. Light emission in the longer wavelength of 1.55 μm is reported to be achieved by quantum confining InN or alloying with GaN [8]. InN films of *a*-plane are found to have the property of emitting intense terahertz radiations [9]. Ultrathin InN field effect transistor has shown the ability to sense the anion in the aqueous solutions [10]. The significant properties of the elemental nitrides have made the alloy $In_xGa_{1-x}N$ to be promising source in variety of applications. Growth of indium rich $In_xGa_{1-x}N$ is found to be difficult task as the difference in the interatomic spacing between InN and GaN is large. The precipitates of metallic indium during the synthesis also restricts the increase of its composition in $In_xGa_{1-x}N$ alloy [11].

In recent years, the nanostructures of III-nitrides are found to show high device performances [12,13]. The fascinating properties of the nitrides have created more interest of growing their nanostructures in variety of methods [14–17]. Only a few reports are available in synthesizing the nanostructures of $In_xGa_{1-x}N$ alloy. Garcia et al. reported the synthesis of $In_xGa_{1-x}N$ micro crystals by pyrolysis reaction of Indium gallium complex salt in heated ammonia atmosphere [18]. Gopalakirishnan et al. [19] have synthesized $In_xGa_{1-x}N$ nanoparticles by co-precipitation followed by reacting with ammonia at 750 °C. Schwenzer et al. [20] reported the synthesis of InN and GaN nanoparticles from an inorganic ammonia fluorine precursor. Choi et al. [21] prepared Ga-In-N composite from the decomposition of metal azides. Compared to above reported methods hydrothermal method can yield particles with controlled size, shape and distribution of the particles. Since hydrothermal method is a well-developed method for water based syntheses of nanomaterials they are environmentally benign than other methods like solvothermal methods with organic materials such as toluene, benzene as solvents.

In this article, we report the synthesis of GaN, InN and InGaN

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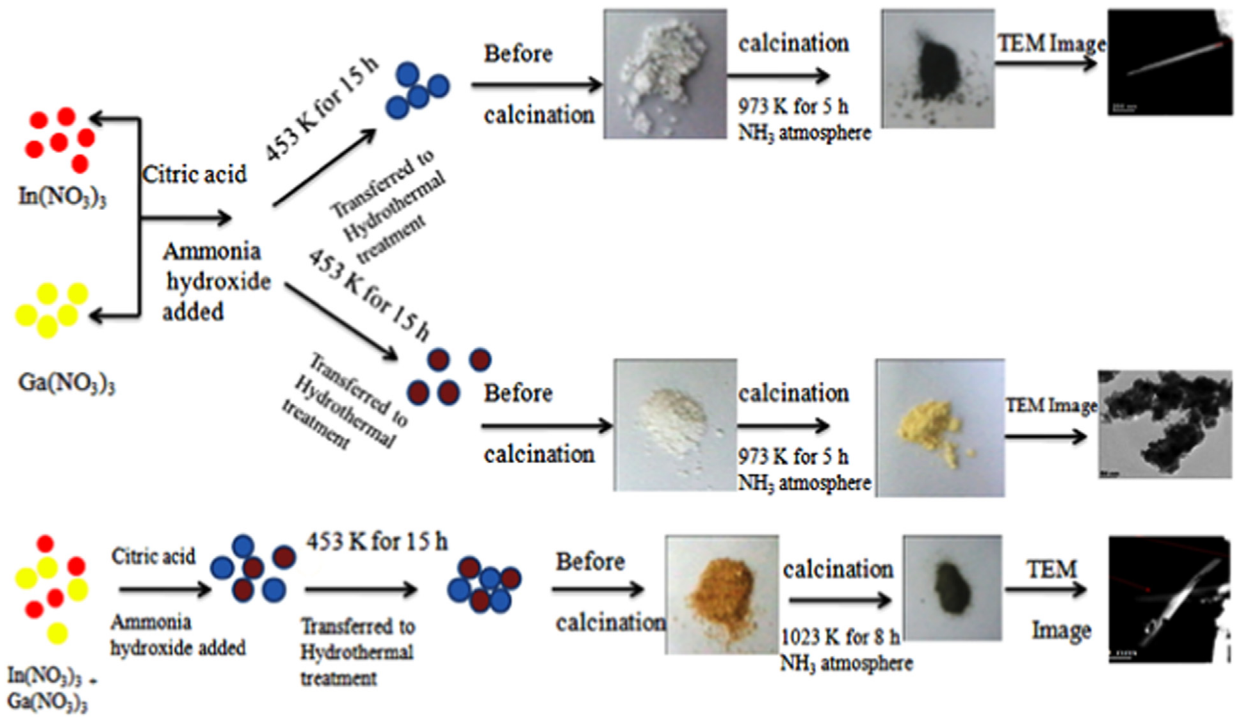

Fig. 1. Schematic diagram for the formation mechanism of GaN, InN and $In_xGa_{1-x}N$.

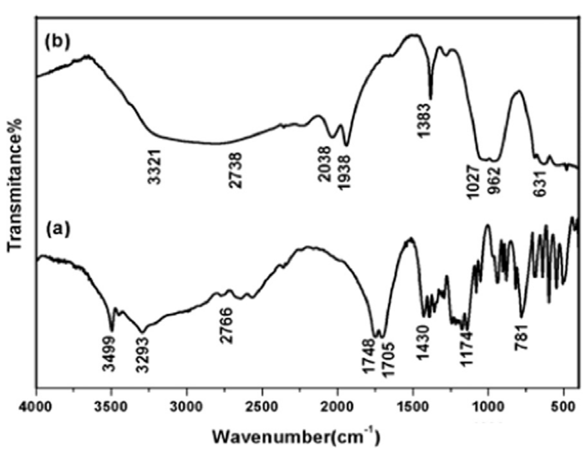

Fig. 2. Fourier Transform infrared spectrum of (a) Citric acid, (b) Ga-Citrate-complex.

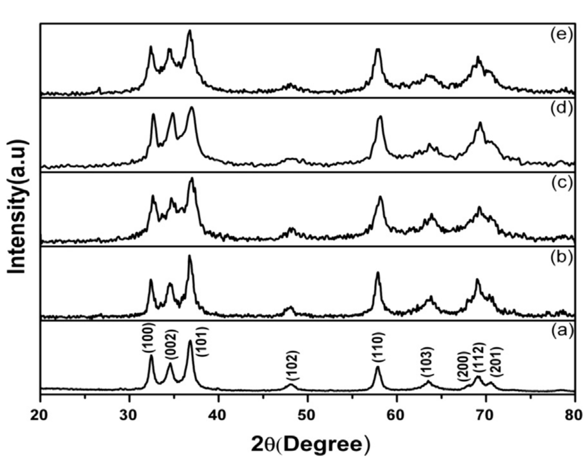

Fig. 3. XRD pattern of GaN prepared at different temperatures (a) 1173 K, (b) 1120 K, (c) 1073 K, (d) 1023 K and (e) 973 K.

Table 1
The *FWHM* of the (101) plane, lattice parameter (*a* and *c*) and crystallite size of GaN nanoparticles relative to the nitridation temperature (1173–973 K).

Nitridation Temperature (K)	*FWHM of* (101) *Plane*	*Lattice constants* (Å)		*Average crystalline Size* (nm)
		a	*c*	
973	0.989	3.172	5.199	92
1023	0.964	3.183	5.184	94
1073	0.835	3.187	5.196	110
1120	0.769	3.189	5.188	115
1173	0.766	3.186	5.191	118

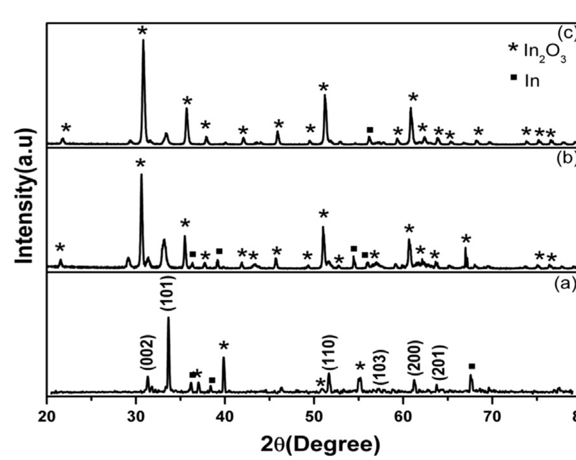

Fig. 4. XRD pattern of InN prepared at different temperatures (a) 973 K, (b) 923 K and (c) 873 K.

nanostructures via hydrothermal assisted formation of metal citrate complex followed by ammonolysis. To the best of our knowledge this is the first report for the synthesis of InN nanorods