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GaN Nanofibers based on Electrospinning: Facile Synthesis, Controlled Assembly, Precise Doping and Application as High Performance UV Photodetector

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ADVANCED MATERIALS *2009, 21, 227–231*

Introduction

- Group III N alloys,especially GaN, have huge potential in semiconductor industry
- Conventional methods (catalysts,templates etc) produces randomly positioned and different diametered NWs and the metal catalysts incorporate into the NWs
- Electrospinning provides continuous fibers with low cost, high efficiency and controlled assembly
- Electrospun GaN nanofibers shows very high efficiency to the UV photodetection

Facile synthesis

Steps involved for the fabrication of GaN nanofibers

1) Preparation of PVP- $Ga(NO_3)_3$ electrosun composite nanofibers from the solution of PVP and $Ga(NO_3)_3$ at a high voltage of 20 kV with a distance of 20 cm and a constant flow rate of 1 mL h^{-1}

2) Calcination of the composite nanofiber to 500 ^0C for 4 hr to form Ga_2O_3 nanofiber

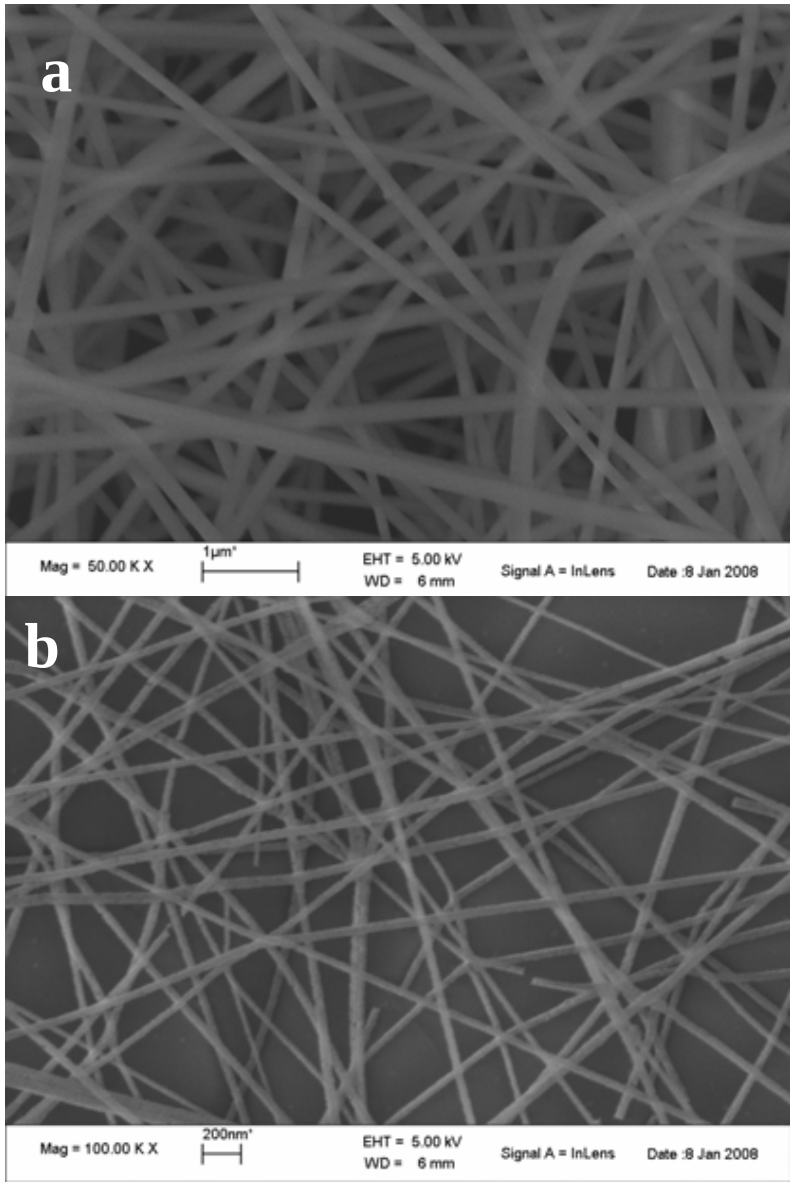
3) In situ conversion of Ga_2O_3 nanofiber into GaN nanofiber in NH_3 atmosphere at 850 ^0C for 2 hr at a heating rate of 2 ^0C ,the color has changed from white to yellowish

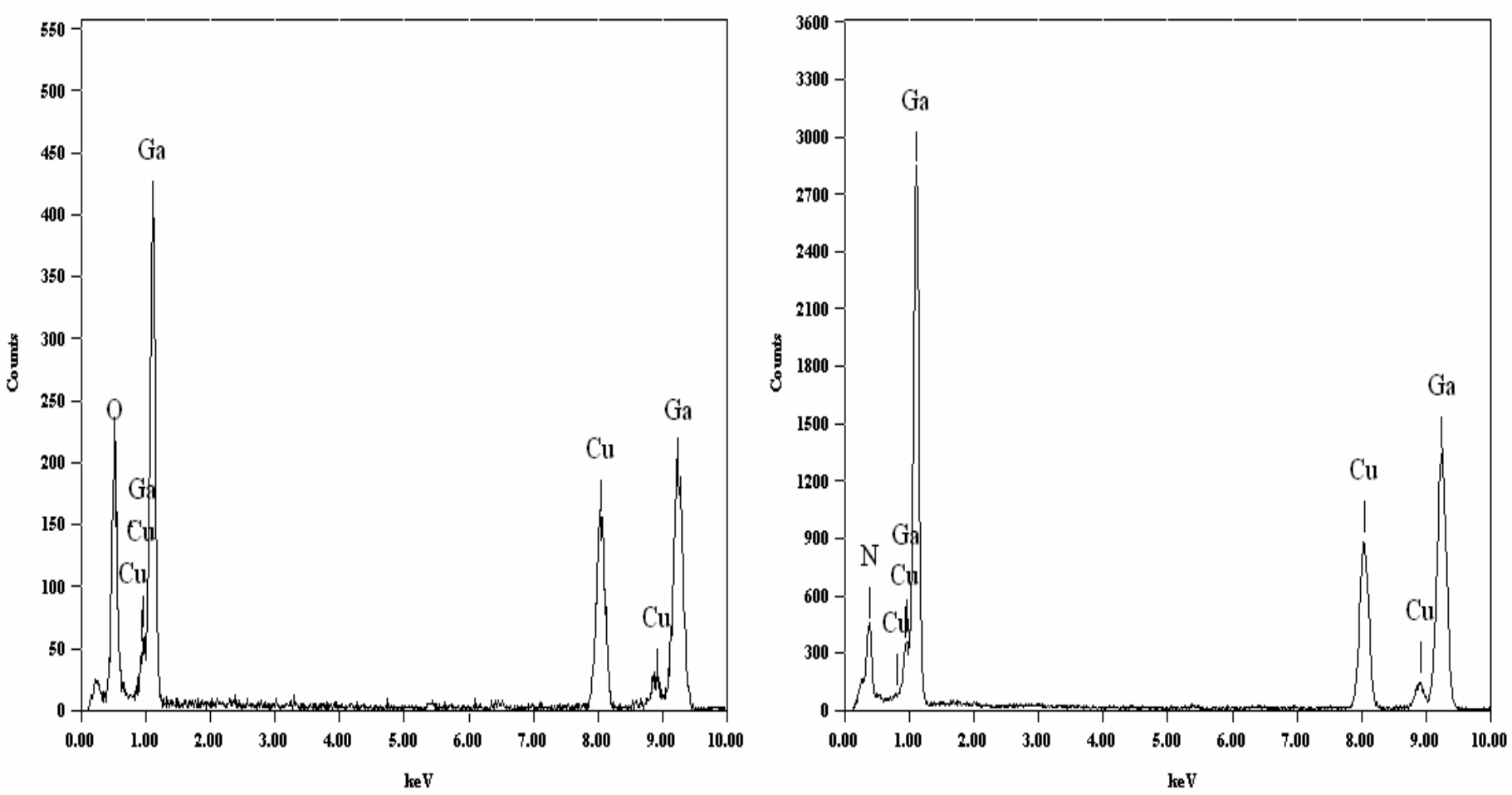
Characterization studies:

SEM images of

(a) Electrospun PVP/$Ga(NO_3)_3$ precursor nanofibers;

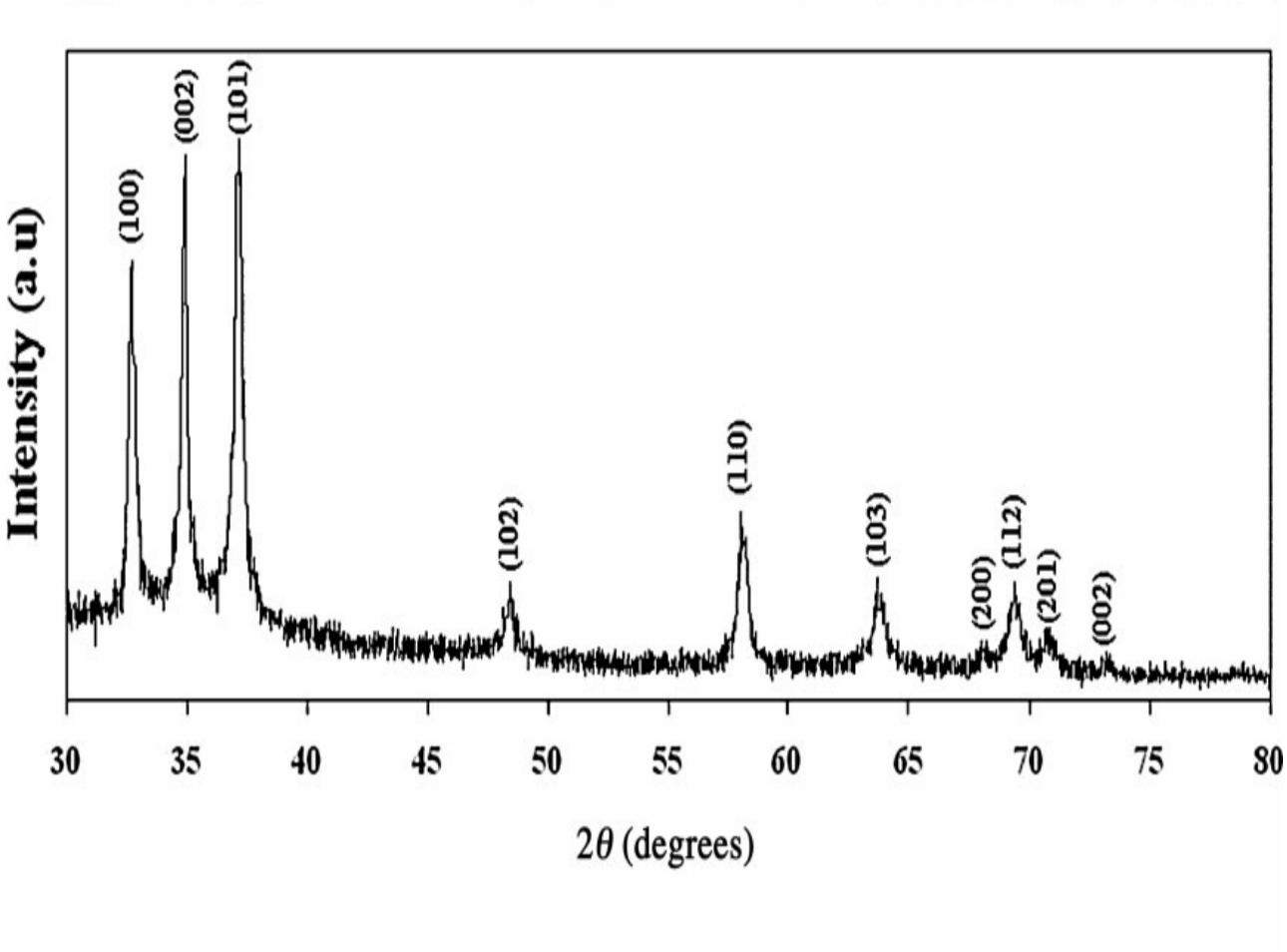
(b) Ga_2O_3 nanofibers



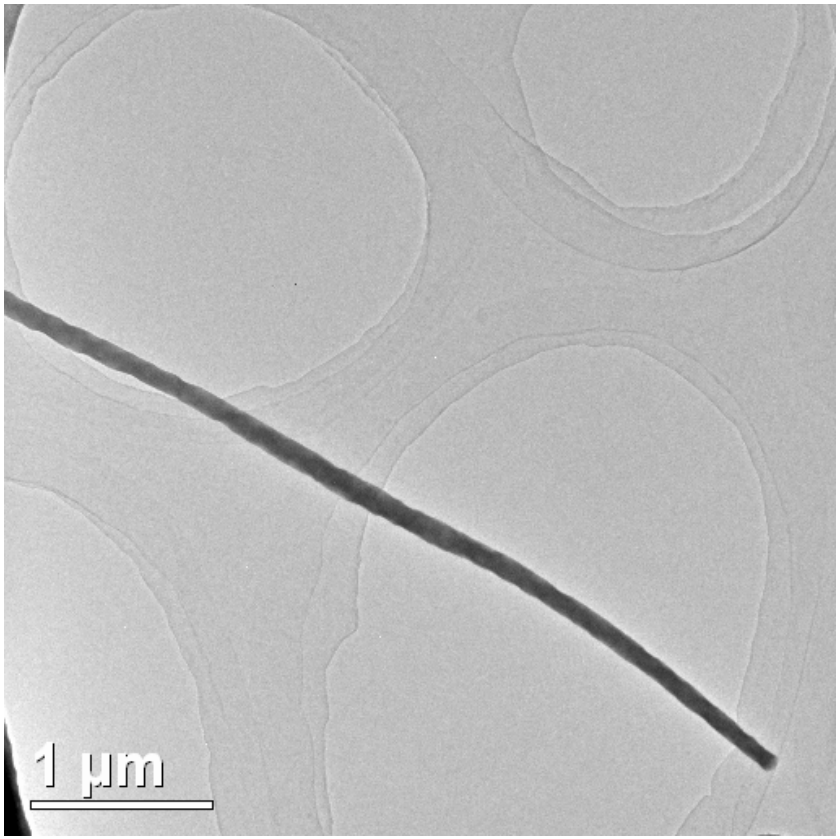


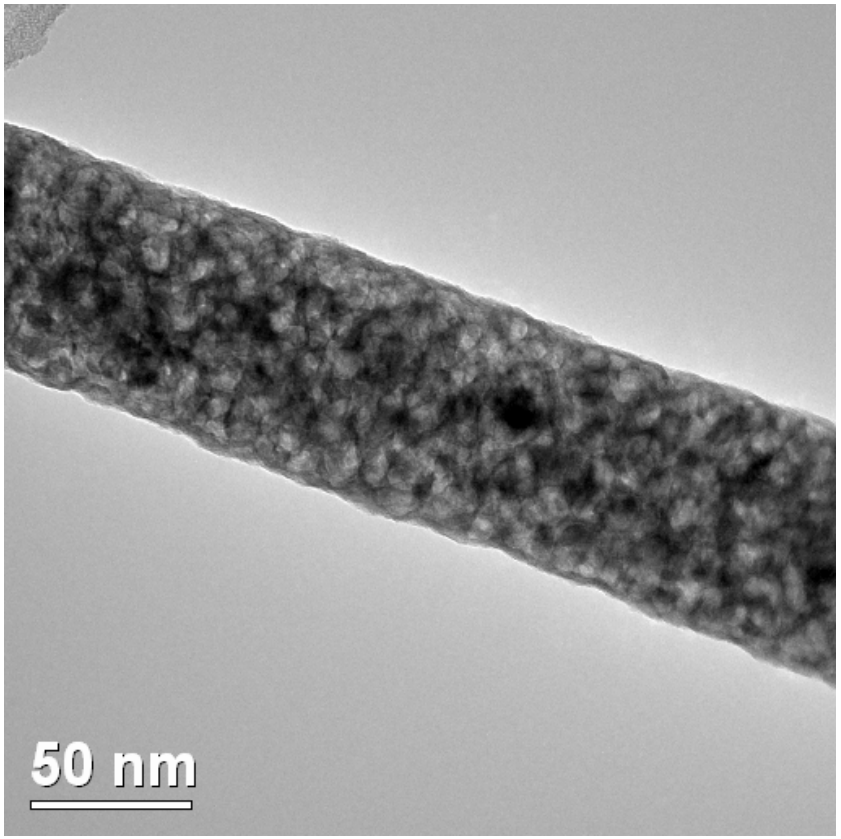
(a) (b)

EDX spectra of (a) Ga_2O_3 nanofibers, (b) GaN nanofibers



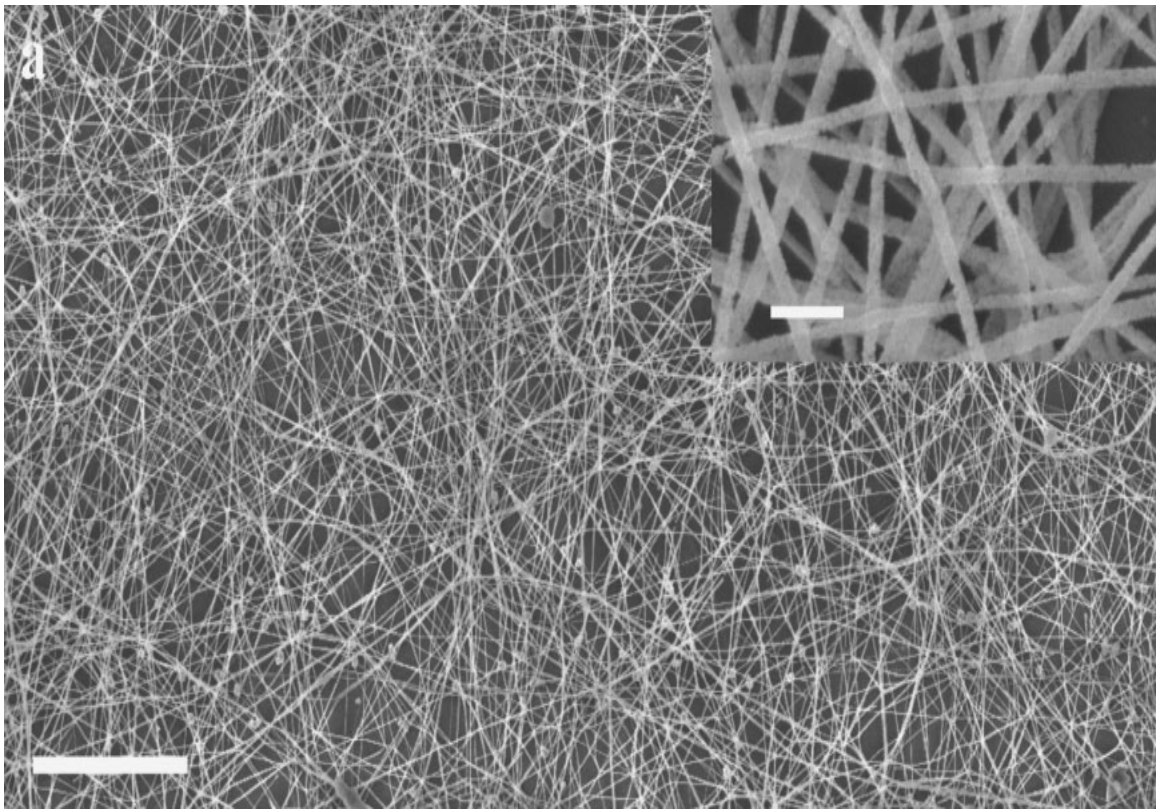
XRD pattern of synthesized GaN nanofibers





TEM images of synthesized Ga_2O_3 nanofibers

Nanofibers have smooth surface and an average diameter of 60 nm

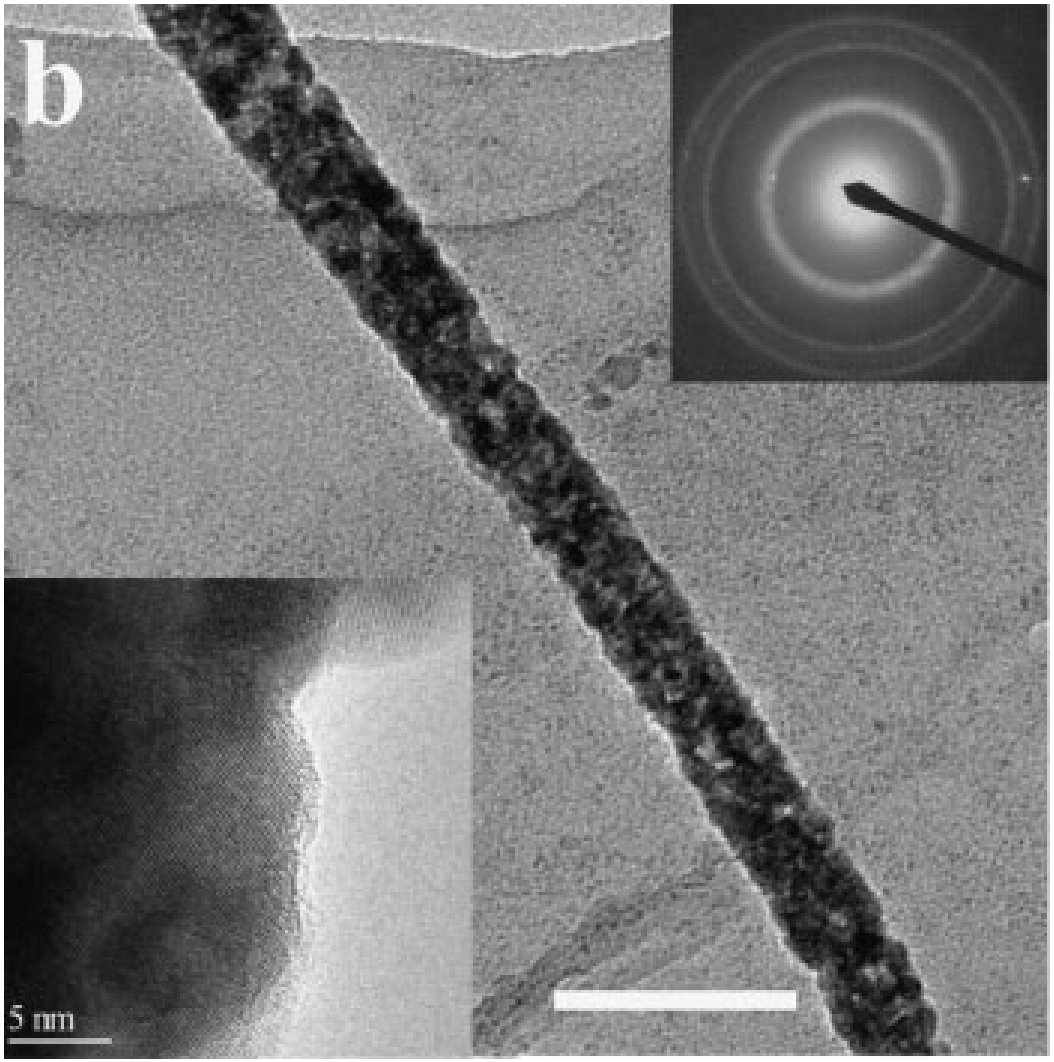


SEM images of synthesized GaN nanofibers

•Ultrahigh aspect ratio with length around some cm scale and diameter 40 nm

•Less smooth fibers

•SAED reveals the polycrystalline nature

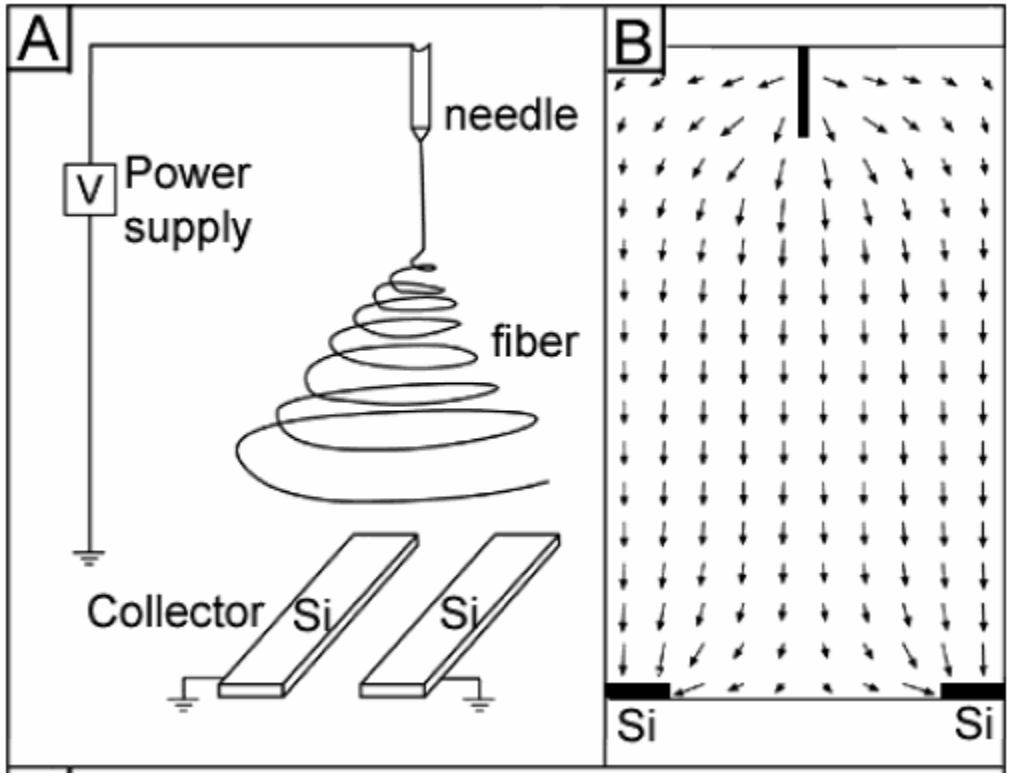


TEM image of a single GaN nanofiber with SAED pattern

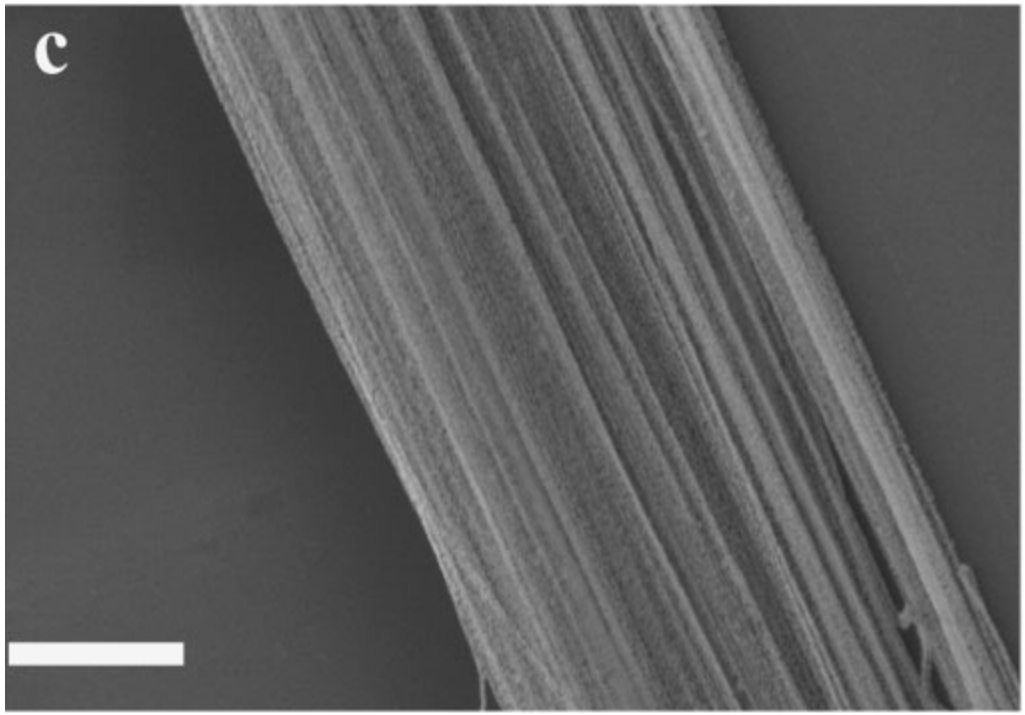
Controlled Assembly

•A modified fiber collector is used, fabricated by putting two strips of conductive silicon in a side by side parallel arrangement

•Fibers are aligned in between the electrodes

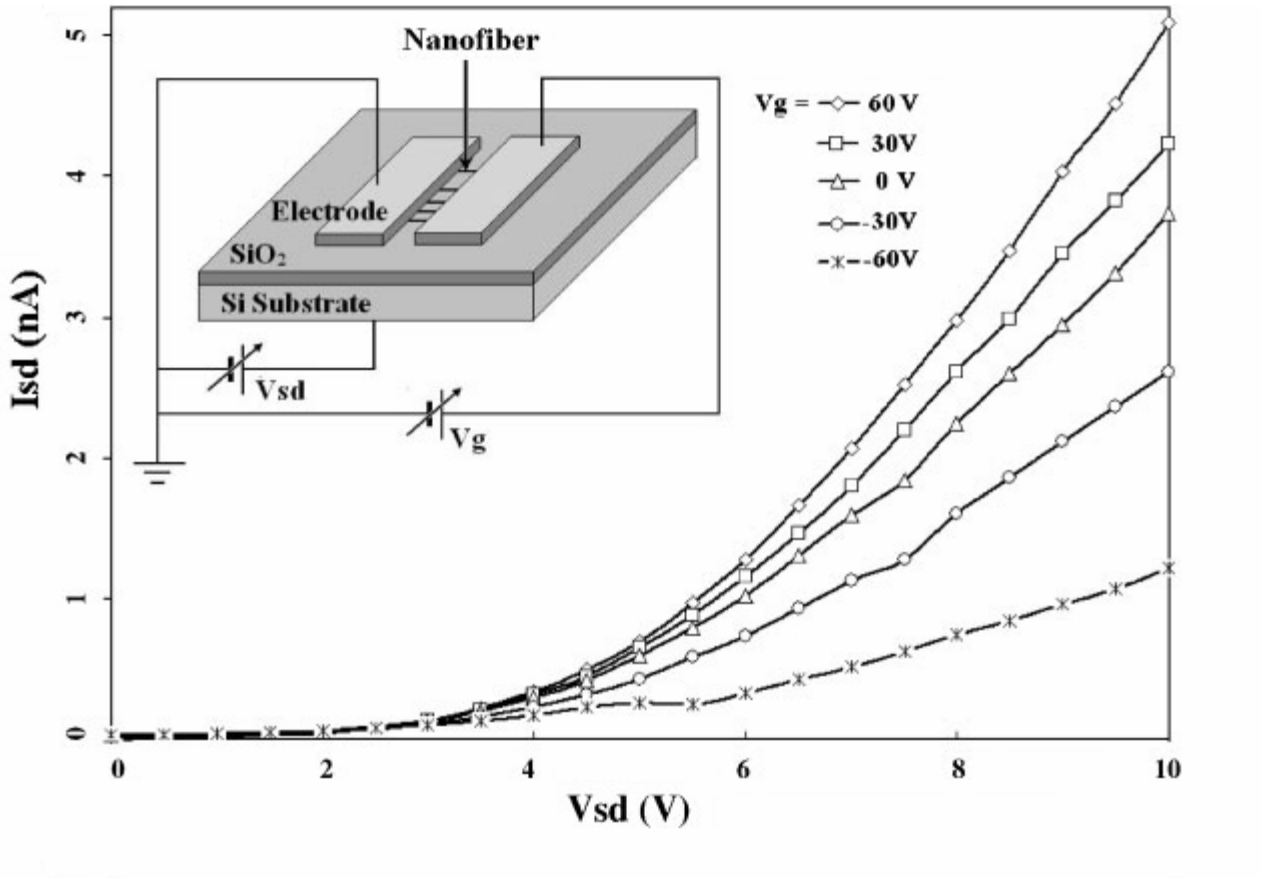


(A) Schematic illustration of the set-up for electrospinning that was used to generate uniaxially aligned nanofibers. The collector contained two pieces of conductive silicon stripes separated by a gap. (B) Calculated electric field strength vectors in the region between the needle and the collector. The arrows denote the direction of the electrostatic field lines.



SEM image of a bundle of oriented GaN nanofibers

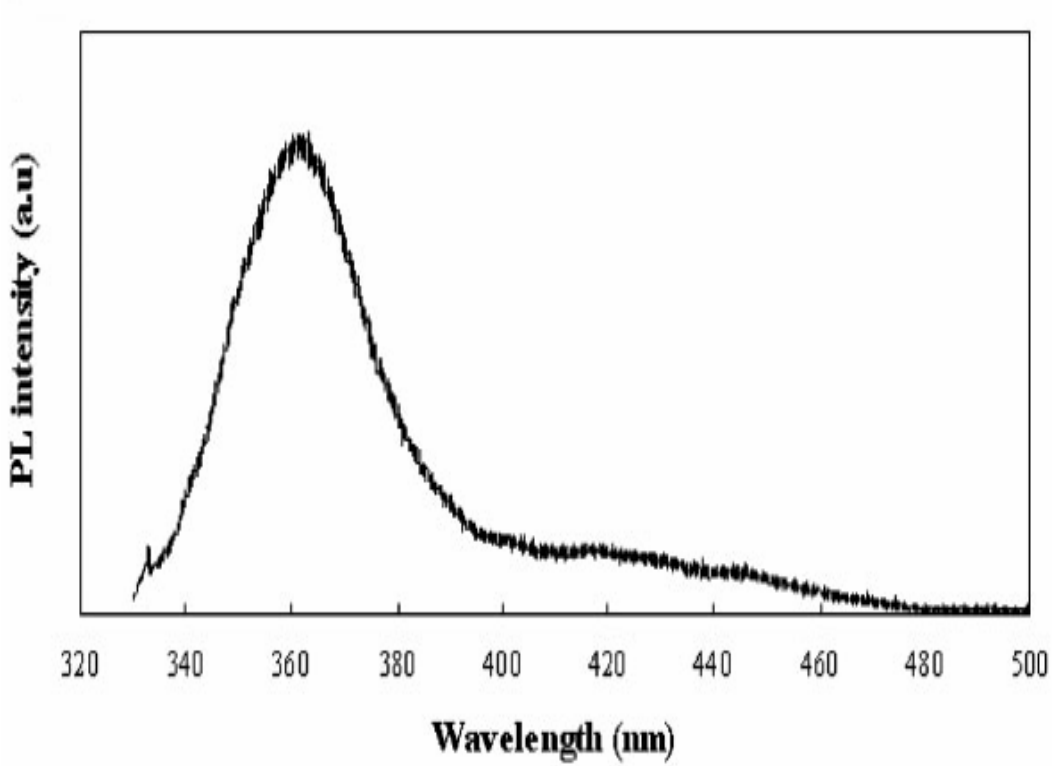
GaN nanofiber FET configuration



Conductance increases for V_g greater than zero and decreases for V_g less than zero shows that GaN nanofiber is intrinsic n-type and which is due to the nitrogen vacancies and oxygen impurities

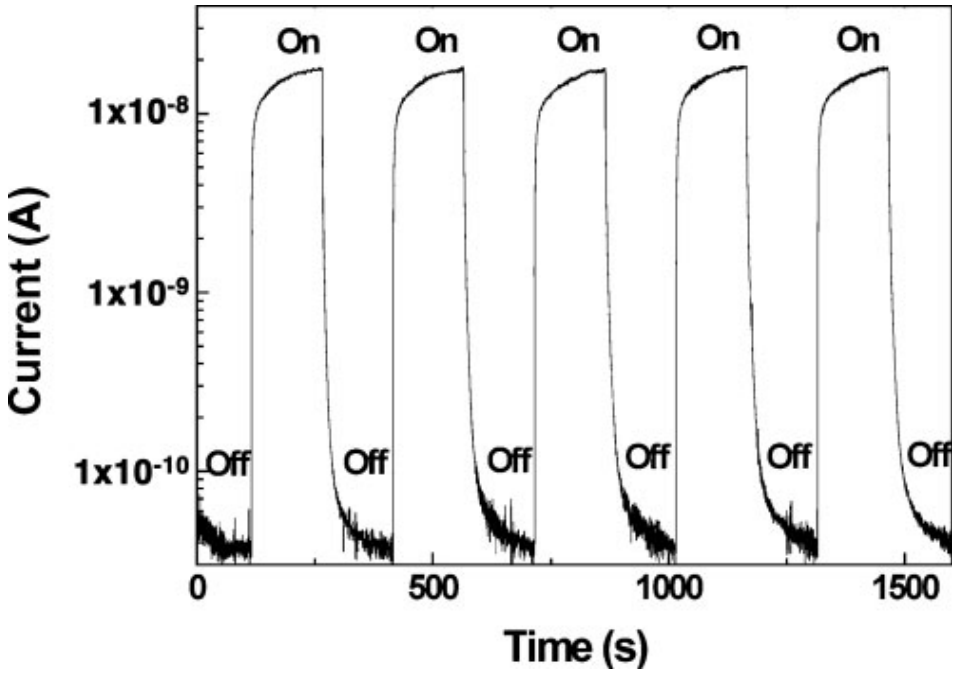
Photoluminescence spectroscopy

- Excitation wavelenth 325 nm
- Emission wavelenth 363 nm
- Band gap energy 3.42 eV (Bulk GaN 3.4eV)



UV Photodetection application

- Wide direct band gap
- Nanometer- scale dimension
- Ultrahigh aspect ratio
- Polycrystalline structure
- Rough surface



Photoconductance response of a GaN nanofiber FET upon pulsed illumination from a 254 nm wavelength UV light with a power density of 3 mW cm^{-2}

•Current (I_{sd}) rises rapidly from 0.03 to 25 nA(830 times) upon exposure of UV light and falls to the initial state when UV switched off while for a single crystal GaN NW grown by CVD method has smaller response(78)only to UV light

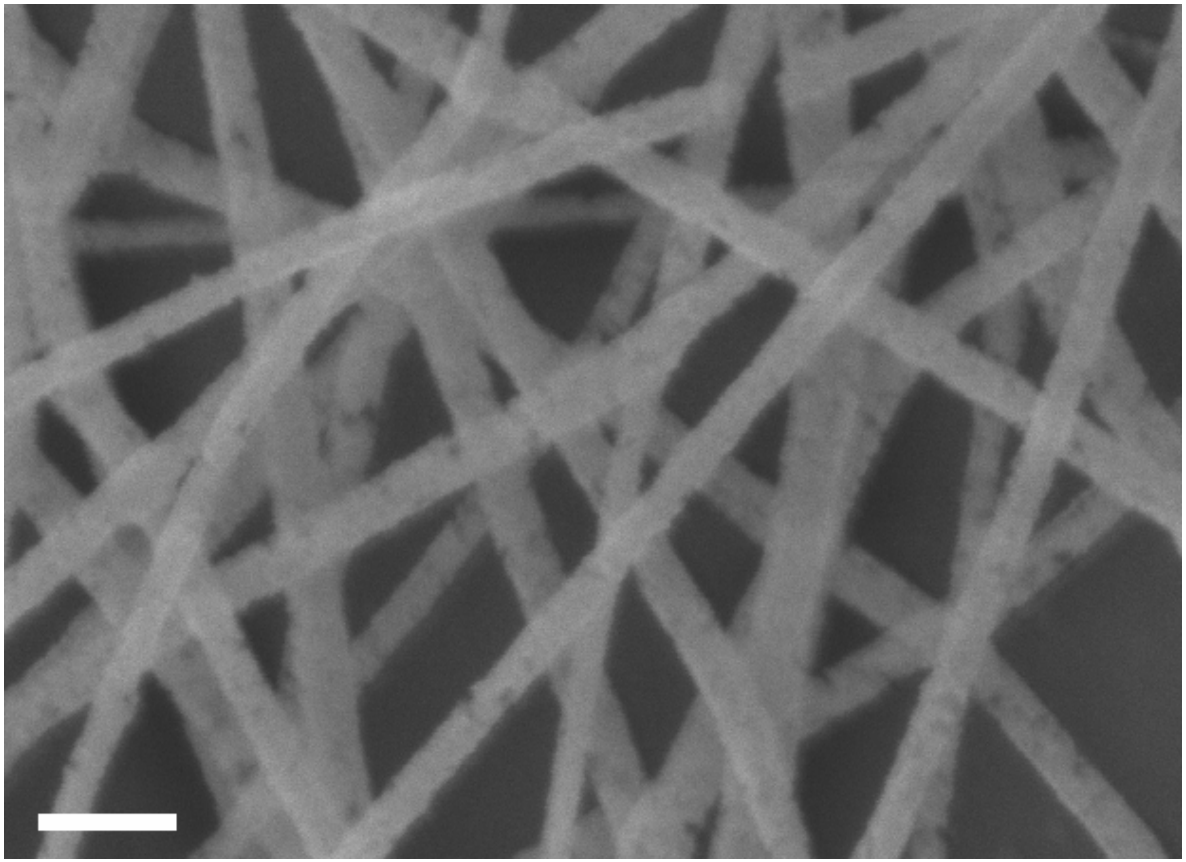
•Polycrystalline structure and rough surface lead to high surface to volume ratio which results in more photogenerated carriers

•High sensitivity, fast response and reversibility

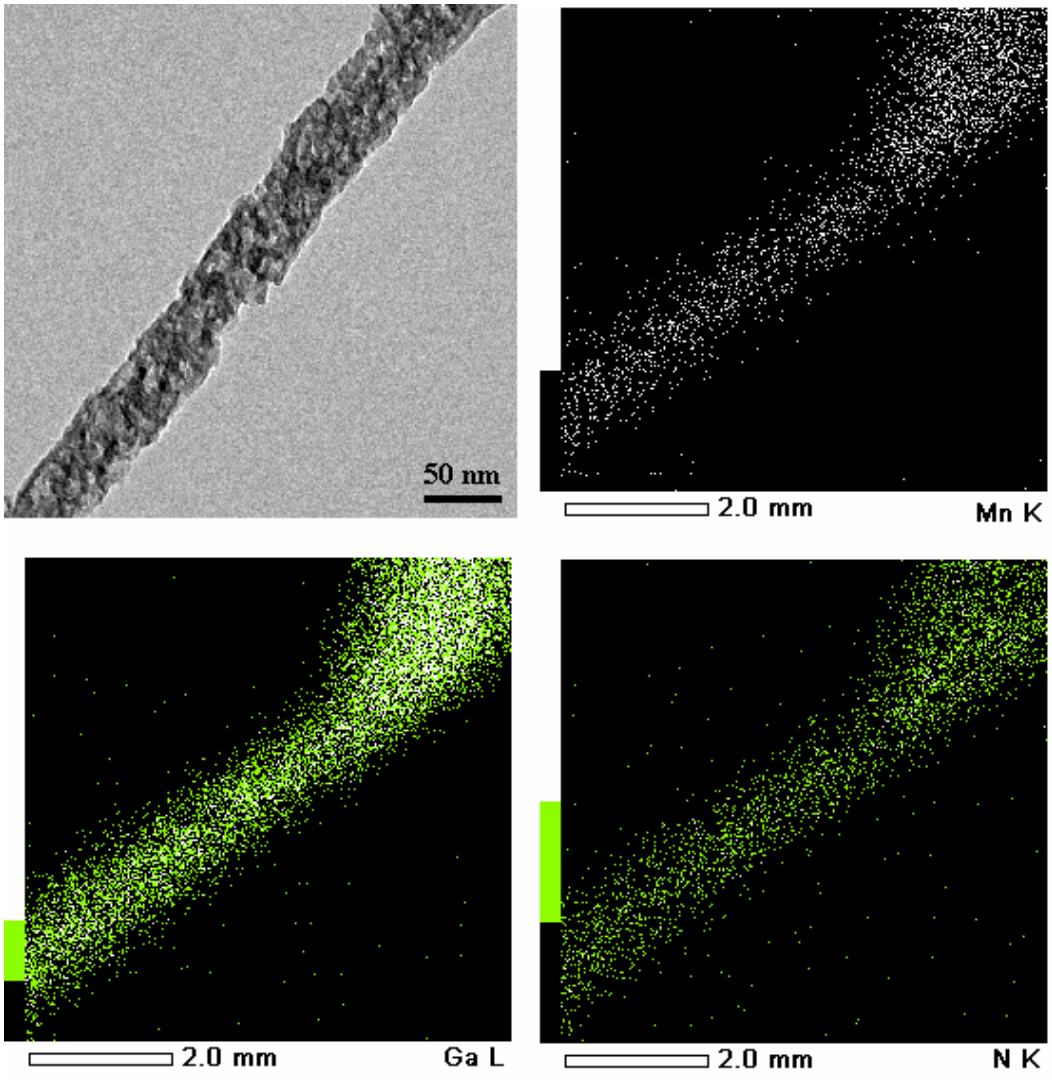
•Solar UV monitoring, UV astronomy, source calibration, flame sensors and securing space to space communication

Precise doping

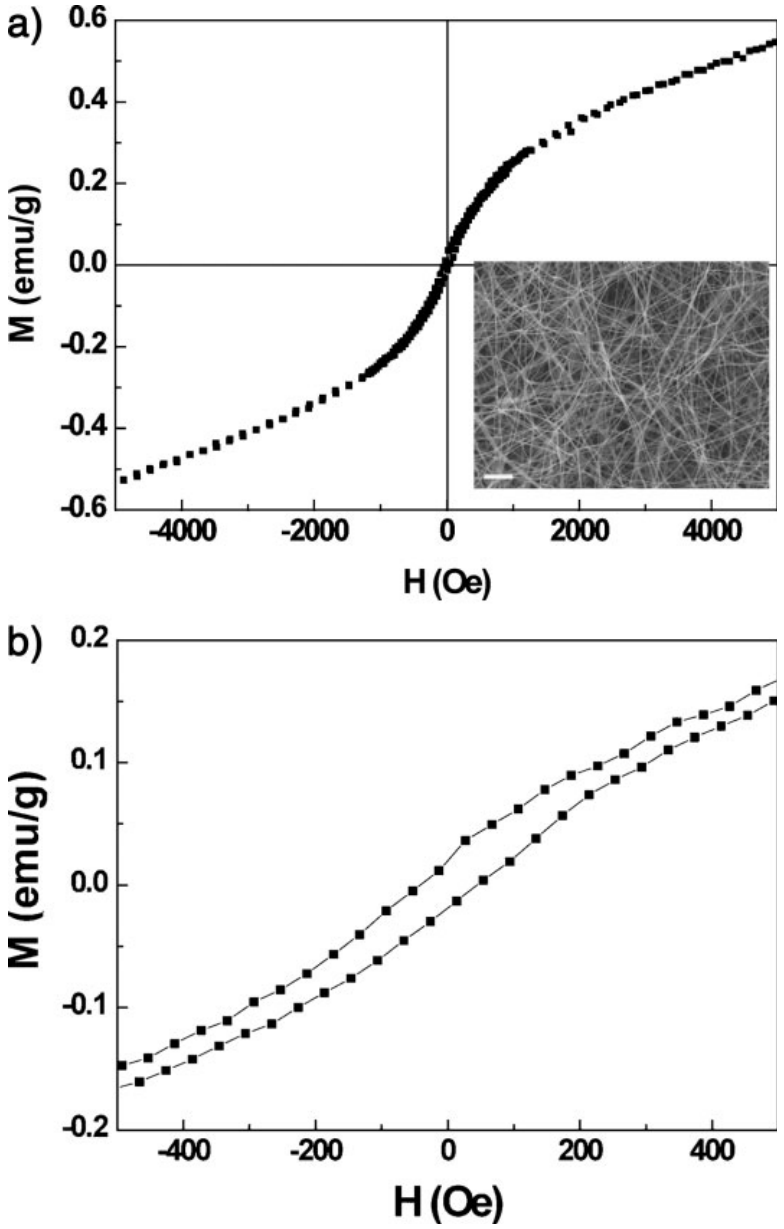
- Doping of other elements into the nanofiber at the solution phase results in change of their physical properties and arising of new properties
- Ultra-thin Mn-doped GaN nanofibers can be synthesized by adding suitable amount of $Mn(NO_3)_2$ into the precursor solution followed by electrospinning and annealing
- EDX analysis shows that the Mn concentration approaches the same as that designed and Mn distributed uniformly within the nanofibers
- Mn doped GaN nanofibers shows the magnetic hysteresis and remanence which reveals its ferromagnetic behavior
- This shows a new way to the synthesize of diluted magnetic semiconductor (DMS) nanofibers effective for constructing spintronic nanodevices



SEM image of $Ga_{0.9}Mn_{0.1}N$ nanofibers. Scale bar is 100 nm



TEM image (a) and elemental maps of synthesized Mn doped GaN nanofibers: (b) Mn map; (c) Ga map; (d) N map



a) Magnetization loops of the nanofibers measured at room temperature. b) The magnetization in the low-field region. The hysteresis behavior and remanence can be observed. The inset in (a) is a typical SEM image of the samples

Summary:

• High quality GaN nanofibers have been synthesized by electrospinning from the solution of PVP and $Ga(NO_3)_3$ followed calcination and annealing in the NH_3 atmosphere.

• Wide direct band gap(3.42 eV), nanometer- scale dimension,ultrahigh aspect ratio,polycrystalline structure, rough surface and n-type semiconductor

• GaN nanofibers have application in UV light sensors with superior sensitivity, fast response and reversibility

• Since it is solution based synthesis, doping with other elements is easy and results in new physical properties and improvement of existing ones.

- Synthesis of Tellurium based nanofibers of similar kind from a Tellurium precursor like TeO_2 and polymers
- Doping of the Tellurium with other elements in different proportions having magnetic properties, photoluminescent properties, conductivity properties
- Electrospinning of conducting polymers with and without doped elements and their conductance studies

Thank you