Materials Letters 217 (2018) 288–291

Contents lists available at ScienceDirect

Materials Letters

journal homepage: www.elsevier.com/locate/mlblue

Fabrication and UV photoresponse of GaN nanowire-film hybrid films on sapphire substrates by chemical vapor deposition method

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ARTICLE INFO

Article history:
Received 30 November 2017
Received in revised form 12 January 2018
Accepted 17 January 2018

Keywords:
GaN nanowires
Hybrid films
UV detectors
Chemical vapor deposition

ABSTRACT

Hybrid films composed of GaN nanowires and GaN films were prepared on sapphire substrates by chemical vapor deposition. The GaN films and GaN nanowires are all indexed to the hexagonal wurtzite structure. The photoluminescence spectra of GaN nanowire-film hybrid films are composed of a strong ultraviolet emission peak (365 nm) and a weak yellow luminescence band (~600 nm). The UV detector based on GaN nanowire-film hybrid films shows a high responsivity of ~2.5 A/W at 360 nm and a fast response speed of ~22 μs.

1. Introduction

As a significant III-V wide gap semiconductor, wurtzite GaN with a direct bandgap of 3.4 eV has gained substantial attention due to its outstanding optical and electrical properties. GaN nanowires have enormous potentials as fundamental building blocks for nanoscale UV detectors [1], nanoscale LEDs [2] and photocatalysts [3]. In general, UV detectors based on GaN nanowires have high photoconductivity properties [4], but large surface-to-volume ratio of nanowires also significantly increases the response time [5]. Compared with GaN nanowires, UV detectors based on GaN films have usually been reported in terms of low dark current and ultrafast response, due to the lack of surface states [6]. Therefore, a new UV detector based on hybrid films composed of GaN nanowires and GaN films may be beneficial to improve the photoresponse performance.

In this paper, we will report on the fabrication and UV photoresponse properties of GaN nanowire-film hybrid films. The UV detector based on the hybrid films exhibits a high responsivity of ~2.5 A/W at 360 nm and a fast response speed of ~22 μs.

2. Experimental section

GaN nanowire-film hybrid films were synthesized on sapphire (0001) substrates by chemical vapor deposition (CVD) method. Ga_2O_3 films were pre-deposited by sputtering Ga_2O_3 target in mixed atmosphere of Ar and N_2. The sputtering chamber was evacuated to 3×10^{-4} Pa, and the RF power was set to 90 W. The distance between the target and the substrates was 5 cm. The sputtering time was 2 h with the film thickness of ~200 nm. Then the sputtered Ga_2O_3 films were loaded to CVD systems to prepare GaN nanowire-film hybrid films. The gallium source (99.9999%) was placed on the upstream of the furnace. The synthesis was carried out at 850–1000 °C under a NH_3 gas atmosphere of 120 sccm for 2 h. The GaN samples were characterized by X-ray diffraction (XRD) and scanning electron microscopy (SEM). Optical properties were investigated by photoluminescence (PL).

Two Al electrodes were formed on GaN nanowire-film hybrid films by thermal evaporation using a metal mask. The distance between the two electrodes was set to 100 μm. The current-voltage (I-V) characteristics of the UV detector were characterized in dark and under UV illumination using a Keithley Model 2400 instrument. The spectral responsivity and transient response were also measured.

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https://doi.org/10.1016/j.matlet.2018.01.107
0167-577X/

3. Results and discussion

As published elsewhere, compared with as-sputtered Ga_2O_3 films, nitrogen doping can improve their crystallinity, which is beneficial to the growth of GaN nanowires [7]. Fig. 1 shows XRD patterns of as-grown samples at different temperatures. Three diffraction peaks of (0 0 2), (1 0 1) and (0 0 4) are all indexed to a hexagonal wurtzite GaN (JCPDS: 76-0703, ICDD: 50-0792). No diffraction peaks from the Ga_2O_3 thin film are found in these samples, which indicates that the Ga_2O_3 thin film has decomposed completely. The GaN nanowire-film hybrid films prefer to c-axis orientation while other planes are relatively restrained owing to GaN (0 0 2) planes possessing the lowest surface energy density. The diffraction intensity reaches a maximum at 900 °C, revealing that the GaN sample at 900 °C yields a better crystal quality.

However, when the temperature is further increased to 1000 °C, the intensity decreases and the crystalline quality significantly degrades.

Fig. 2 shows the surface morphologies of GaN samples at different growth temperature. In Fig. 2(a), less GaN nanowires and nanorods are formed on the substrates, resulting from the lower atom diffusion of Ga and lower decomposition of ammonia at a low temperature of 850 °C [8]. Fig. 2(b) shows the typical SEM image of the GaN nanowires, which are randomly distributed and crossed each other on the surface. With increasing the temperature, the dissociated ammonia increases, and more N atoms will be transported to the surface of substrate by carrier gas, which is beneficial to the formation of GaN nanowires [9]. As shown in Fig. 2(c) low quality GaN nanowires and agglomeration-like nanorods arbitrarily disperse on the surface.

However, a further increase of the temperature up to 1000 °C, GaN nanowires or GaN nanorods have not formed and agglomerate into micrograins, which reveals that GaN sublimated at high temperature. Fig. 1(e) shows the cross sectional SEM image of Fig. 1(b), which indicates that the GaN nanowire-film hybrid films were successfully obtained on sapphire substrates, and the thickness of the GaN film is more than 1 μm.

Fig. 3 shows the PL spectra of the as-grown GaN samples. The spectra can be divided into a strong UV spectrum (~365 nm) and a broad yellow emission (~600 nm) band. The UV emission can be attributed to the near band-edge transition [6]. The YL emission band is related to deep level defects [10]. At the temperature of 900 °C and 950 °C, the enhancement in PL intensity may be caused by the strain relaxation in GaN nanowires or nanorods, and induced an increase in the recombination probability of carriers [11]. The

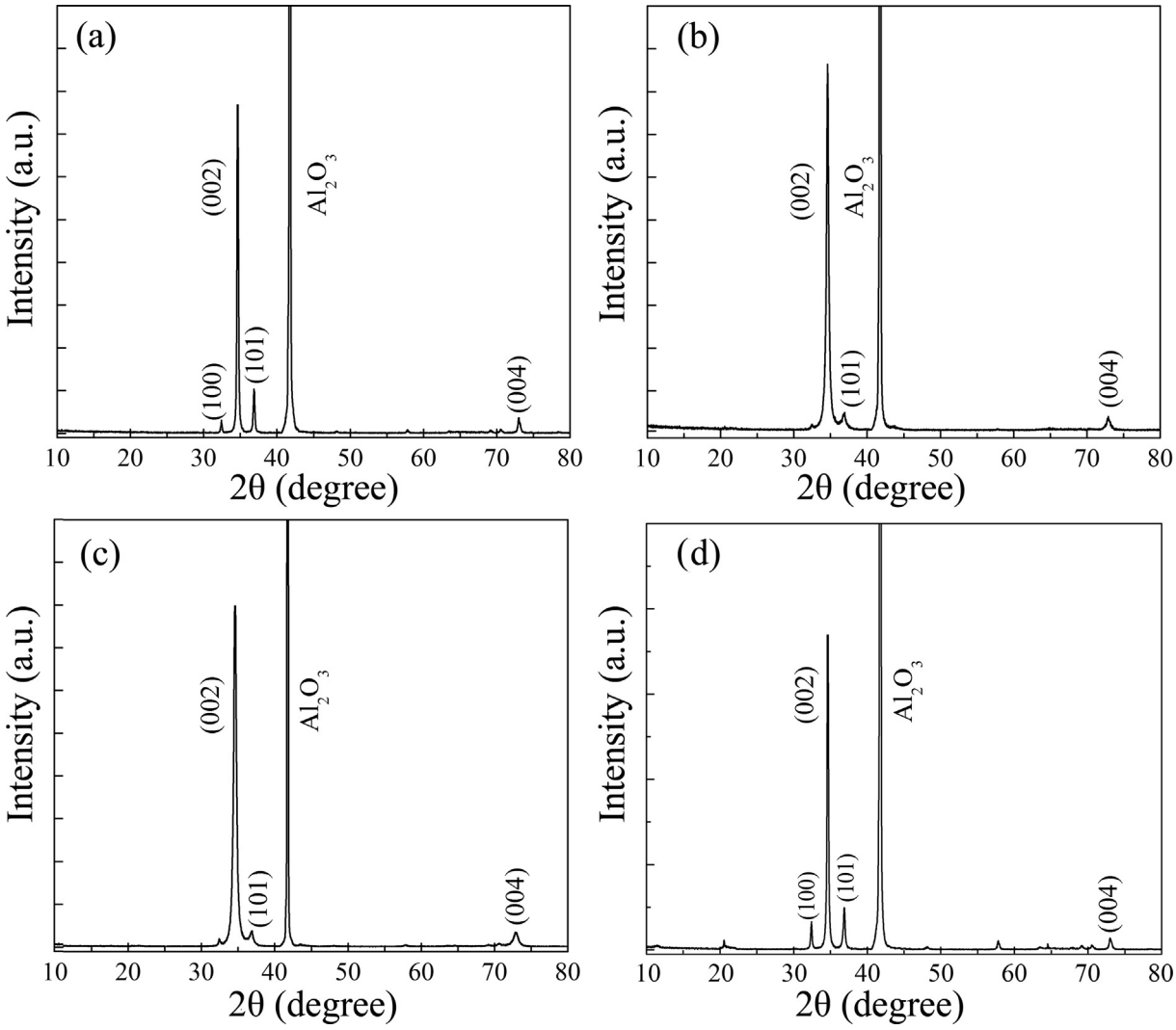

Fig. 1. XRD patterns of as-grown samples at different temperatures: (a) 850 °C, (b) 900 °C, (c) 950 °C and (d) 1000 °C.

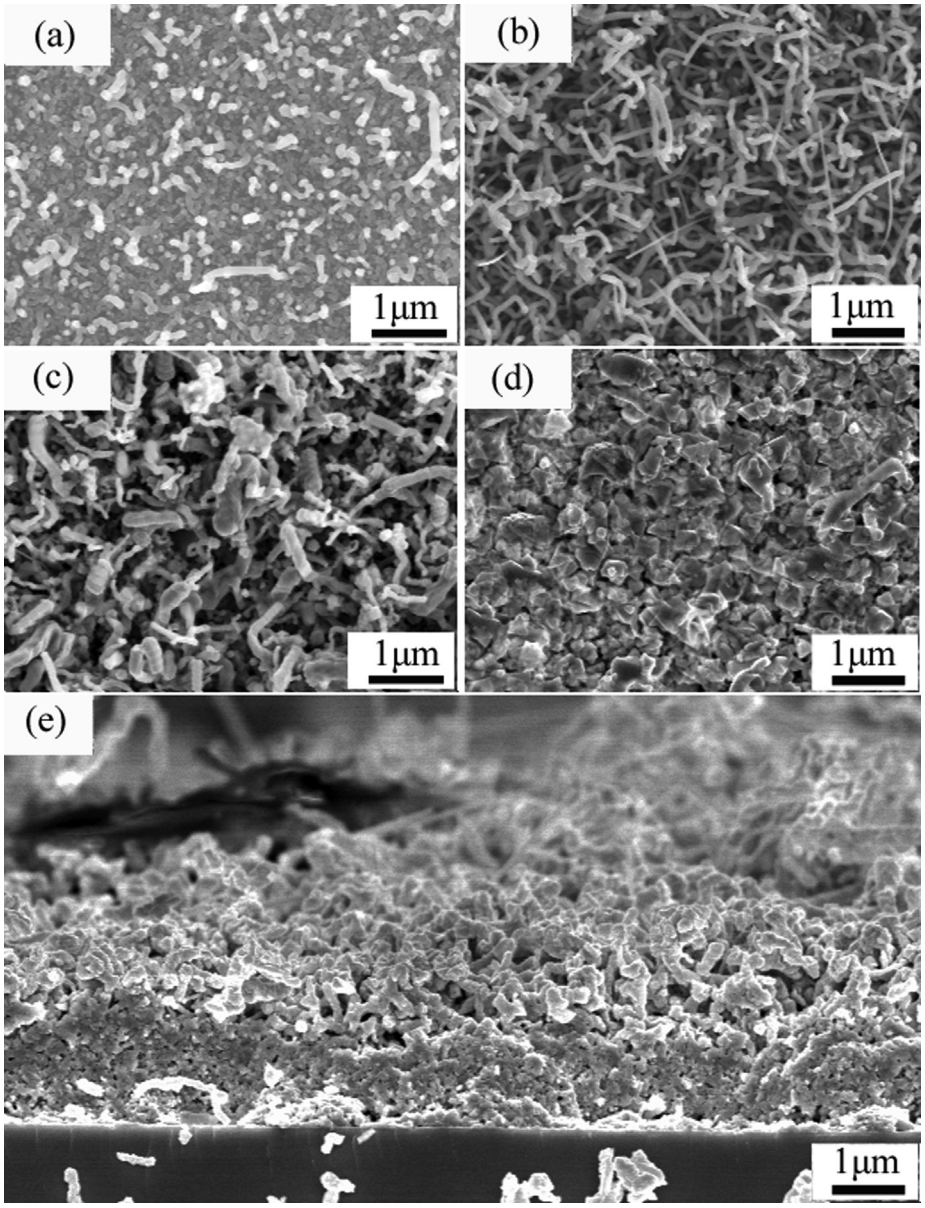

Fig. 2. SEM images of GaN samples at different temperatures: (a) 850 °C, (b) 900 °C, (c) 950 °C, (d) 1000 °C and (e) the cross-section image of the Fig. 2(b).

strongest UV emission peak at the temperature of 900 °C reveals that the GaN nanowire-film hybrid films has a high quality and yields better optical properties, which is consistent with the results of XRD in Fig. 1.

The GaN nanowire-film hybrid films prepared at the temperature of 900 °C is used to fabricate the UV detector. Fig. 4(a) is a schematic diagram of the UV detector based on the hybrid films. The typical I-V characteristics of the UV detector measured in dark and under UV illumination are shown in Fig. 4(b). It is found that the I-V curves of the UV detector exhibit symmetrical behaviors. The dark current of the UV detector is about 2.3 μA, and the photocurrent is increased to about 0.24 mA under UV excitation illumination (λ = 365 nm). In other words, we achieved a 106 times contrast ratio of the photocurrent to dark current for the UV detector. The larger contrast ratio indicates the UV detector with a high signal-to-noise ratio. Fig. 4(c) shows the typical spectral responsivity of the UV detector. The spectral responsivity is relatively larger in the wavelength of 300 to 360 nm, while a sharp cutoff occurs at around 360 nm, which indicates that the

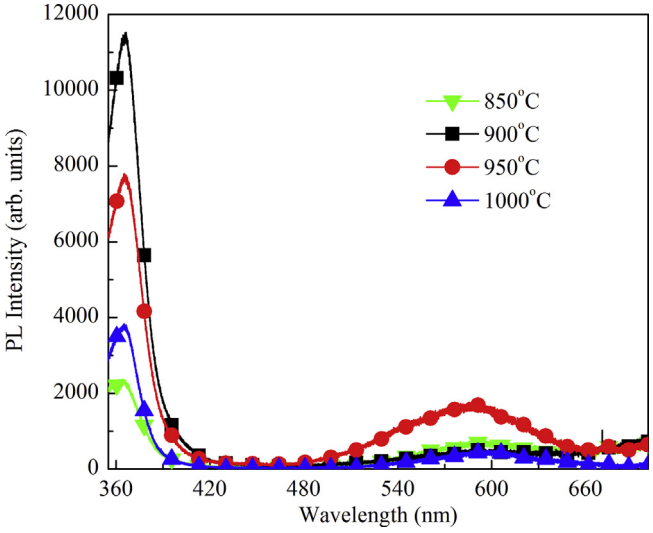

Fig. 3. PL spectra of GaN samples at different temperatures.

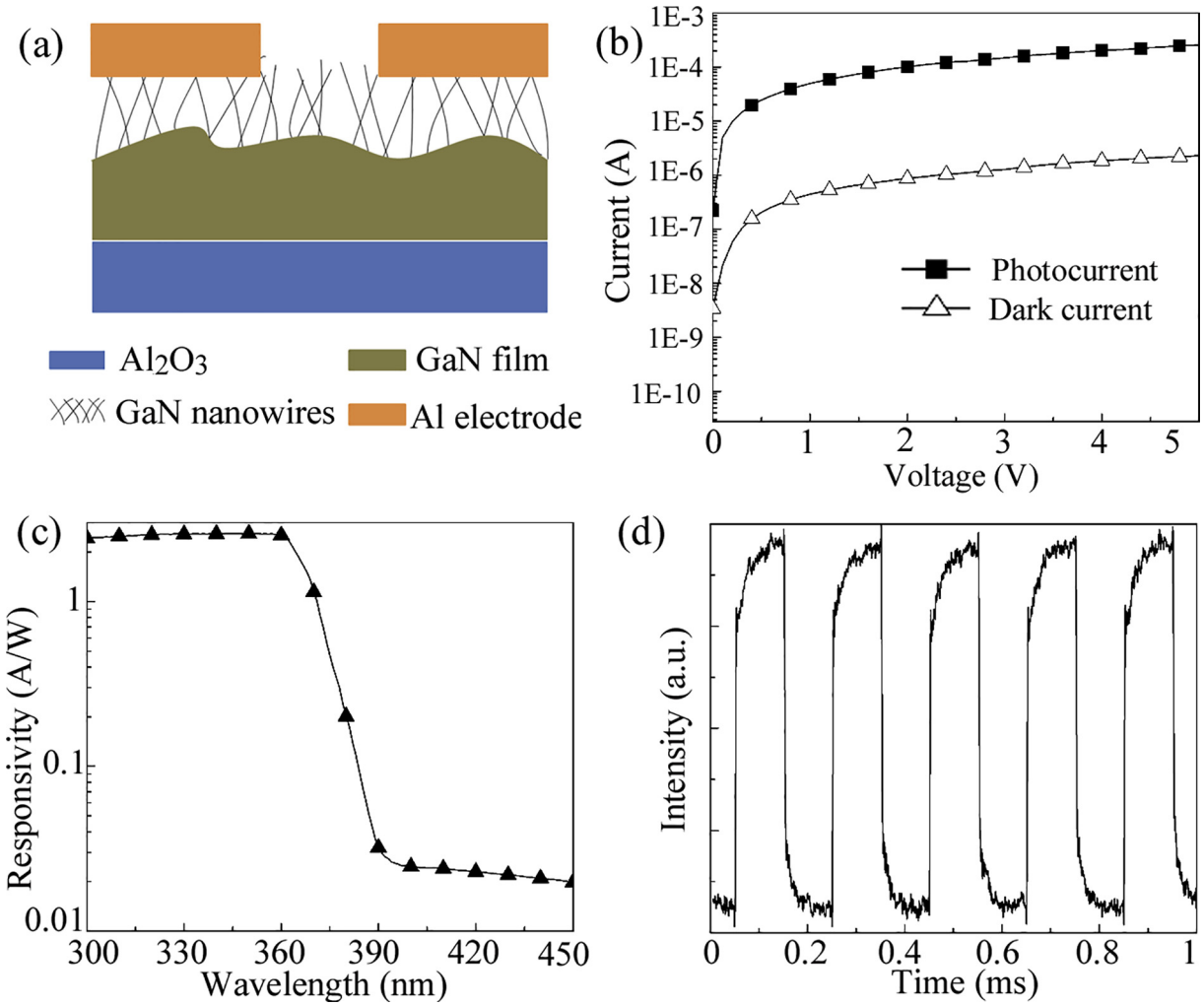

Fig. 4. (a) A diagram of the UV detector based on GaN nanowire-film hybrid films, (b) I-V characteristics, (c) Spectral responsivity, and (d) Transient response.

fabricated UV detector was indeed visible-blind. The highest responsivity is about 2.5 A/W at 360 nm. The response in the UV region is due to the band-to-band transitions in the GaN nanowire-film hybrid films. The response in the wavelength of λgreater than365 nm can be attributed to defects distributed in the hybrid films. UV-to-visible rejection ratio can be defined as the responsivity measured at 360 nm divided by the responsivity measured at 450 nm, and the UV-to-visible rejection ratio of the detector is about 100.

The response behavior should also be considered for detector applications. Fig. 4(d) shows measured transient response of the UV detector, as the UV illumination is switched on and off. The UV detector shows a fast response speed of 22 μs. It is also found that the photocurrent increases rapidly initially and then increases much slower as the UV excitation is turned on.

4. Conclusions

In summary, GaN nanowire-film hybrid films were successfully prepared by CVD method on sapphire substrates, and growth temperature has a great impact on the growth of GaN nanowire-film hybrid films. The hybrid films were helpful to enhance the optical properties of GaN films. The UV detector based on GaN nanowire-film hybrid films exhibited a high responsivity of ~2.5 A/W at 360 nm and a fast response speed of ~22 μs. These results might be useful to fabricate semiconductor nanostructure-film hybrid films and improve the performance of UV detectors.

Acknowledgements

This work was supported by Shenzhen Science and Technology Plan Supported Project (Grant No. JCYJ20140616172915497, JCYJ20160226201232552), and China Scholarship Council (Grant No. 201606125092).

References

[1] X.L. Zhang, Q.Y. Liu, B.D. Liu, W.J. Yang, J. Li, P.j. Niu, X. Jiang, J. Mater. Chem. C 5 (2017) 4319–4326.
[2] Z.L. Wang, Z.B. Hao, J.D. Yu, C. Wu, L. Wang, J. Wang, C.Z. Sun, B. Xiong, Y.J. Han, H.T. Li, Y. Luo, J. Phys. Chem. C 121 (2017) 6380–6385.
[3] B. AlOtaibi, M. Harati, S. Fan, S. Zhao, H.P.T. Nguyen, M.G. Kibria, Z. Mi, Nanotechnology 24 (2013) 175401.
[4] V.M. Kaganer, S. Fernandez Garrido, P. Dogan, K.K. Sabelfeld, O. Brandt, Nano Lett. 16 (2016) 3717–3725.
[5] R.S. Chen, C.Y. Lu, K.H. Chen, L.C. Chen, Appl. Phys. Lett. 95 (2009) 233119.
[6] H. Rabiee Golgir, D. Li, K. Keramatnejad, Q.M. Zou, J. Xiao, F. Wang, L. Jiang, J.F. Silvain, Y. Lu, ACS Appl. Mater. Interfaces 7 (2017) 21539–21547.
[7] R. Sun, H.Y. Zhang, G.G. Wang, J.C. Han, C. Zhu, X.P. Liu, L. Cui, Ceram. Int. 40 (2014) 13967–13970.
[8] A. Menzel, R. Goldberg, G. Burshtein, V. Lumelsky, K. Subannajui, M. Zacharias, Y. Lifshitz, J. Phys. Chem. C 116 (2012) 5524–5530.
[9] J.Y. Moon, H.Y. Kwon, Y.J. Choi, M.J. Shin, S.N. Yi, Y.J. Yun, S. Kim, D.H. Ha, J.Y. Sug, J. Alloy. Compd. 480 (2009) 853–856.
[10] J. Moon, H. Kwon, M. Shin, Y. Choi, H. Ahn, J. Chang, S. Yi, Y. Yun, D. Ha, S. Park, Mater. Lett. 63 (2009) 2695–2697.
[11] V. Ramesh, A. Kikuchi, K. Kishino, M. Funato, Y. Kawakami, J. Appl. Phys. 107 (2010) 114303.