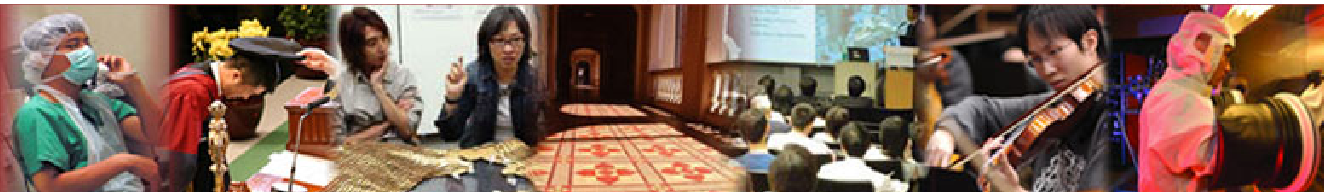
The HKU Scholars Hub The University of Hong Kong 香港大學學術庫



Title	Light-induced instability in current conduction of aluminum nitride thin films embedded with Al nanocrystals
Author(s)	Liu, Z; Chen, TP; Liu, Y; Ding, L; Yang, M; Wong, JI; Cen, ZH; Li, YB; Zhang, S; Fung, S
Citation	Applied Physics Letters, 2008, v. 92 n. 1
Issued Date	2008
URL	http://hdl.handle.net/10722/80558
Rights	This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.; Copyright (2008) American Institute of Physics. This article may be downloaded for personal use only. Any other use requires prior permission of the author and the American Institute of Physics. The following article appeared in (Applied Physics Letters, 2008, v. 92 n. 1, article no. 013102) and may be found at (http://apl.aip.org/resource/1/applab/v92/i1/p013102_s1).

Light-induced instability in current conduction of aluminum nitride thin films embedded with Al nanocrystals

Z. Liu,[a)] T. P. Chen, Y. Liu, L. Ding, M. Yang, J. I. Wong, and Z. H. Cen
School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore 639798, Singapore

Y. B. Li and S. Zhang
School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore 639798, Singapore

S. Fung
Department of Physics, The University of Hong Kong, Hong Kong, People's Republic of China

(Received 6 August 2007; accepted 3 December 2007; published online 2 January 2008)

Al nanocrystals (nc-Al) embedded in AlN thin films have been synthesized by rf magnetron sputtering. The influence of ultraviolet (UV) illumination on electrical characteristics of the nc-Al/AlN thin film system has been investigated. It is shown that the UV illumination could lead to a random change in the conductance of the thin film system. The change in the conductance is attributed to the charge trapping and detrapping in the nc-Al due to the UV illumination. © *2008 American Institute of Physics*. [DOI: 10.1063/1.2828691]

Aluminum nitride (AlN) is an interesting III-V compound with a wide bandgap, high surface acoustic velocity, high thermal conductivity, high dielectric constant, and good thermal and chemical stability. These advantageous characteristics make AlN thin film a promising candidate for applications in surface acoustic wave devices,[1] light-emitting devices,[2,3] and field-effect transistors.[4,5] Recently, AlN thin film embedded with Al nanocrystals (nc-Al) was found to exhibit a memory effect which has a potential application in nonvolatile memory devices.[6] The memory effect is in fact due to the charging and discharging in the nc-Al under certain gate bias. In this work, it is observed that ultraviolet (UV) illumination could also induce charging and discharging in the nc-Al embedded in AlN thin films. As a result of the charging and discharging processes, the current conduction of the nc-Al/AlN thin film system could change under the UV illumination. The situation here is similar to that of Ge nanocrystals embedded in SiO_2 thin films reported recently.[7]

An Al-rich AlN film of 50 nm in thickness was firstly deposited on a *p*-type (100)-oriented silicon wafer, which was precleaned by diluted hydrofluoric acid to ensure that the native oxide and contaminants were removed. The deposition was carried out by rf magnetron sputtering of an ultrapure Al target in a gas mixture of argon and nitrogen with a constant flow-rate ratio of 2:1. The rf power and frequency used in the sputtering were 400 W and 13.6 MHz, respectively. The Si substrate was being heated at 400 °C during the deposition. Then an indium tin oxide (ITO) thin film with the thickness of ~130 nm was deposited on the AlN film to form a semitransparent gate electrode with a diameter of 1.2 mm. The details of ITO deposition and characterization can be found in a previous study.[8] After removing the initial oxide, the backside of the wafer was finally coated with a layer of 500 nm aluminum as the bottom electrode. As can be seen in Fig. 1, the high-resolution transmission electron microscopy (HRTEM) image shows the formation of nc-Al distributed in the AlN matrix. The concentration of the nc-Al was estimated to be in the order of $10^{12}/cm^2$ based on the HRTEM measurement. The size of the nc-Al is in the range of 3–10 nm (more than 70% of nc-Al has the size of 5–8 nm). The current-voltage (*I-V*) and time-domain current measurements were carried out with a Keithley-4200 semiconductor characterization system at room temperature. A Dongwoo Optron TH3 arc lamp together with a Dongwoo Optron DM150i monochromator was used to conduct the UV illumination at the wavelength of 365 nm.

The charging/discharging effect on the current conduction caused by a gate bias or UV illumination has been reported for Si or Ge nanocrystals embedded in various dielectric matrices.[7,9–11] In the nc-Al/AlN thin films, it has been also reported that the current conduction can be changed by the charge trapping in the nc-Al caused by a large electrical bias.[12] In order to study the effect of charging and discharging in the nc-Al caused by UV illumination, the *I-V* measurement and time-domain current measurement were carried out in this work. In the *I-V* measurement, the voltage applied was limited to the range of 0–4 V, while in the time-domain

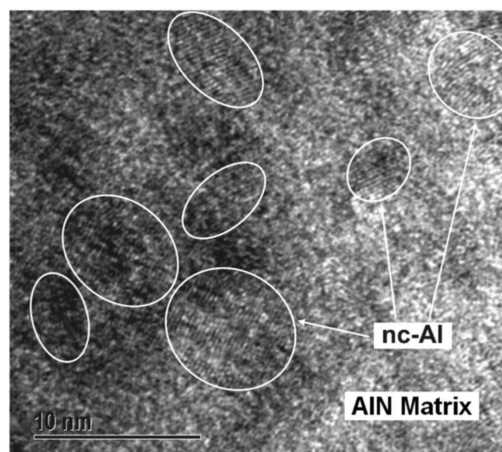


FIG. 1. High-resolution TEM image of AlN thin film embedded with nc-Al.

[a)]Electronic mail: liuz0008@ntu.edu.sg.

 © 2008 American Institute of Physics

Downloaded 16 May 2012 to 147.8.21.150. Redistribution subject to AIP license or copyright; see http://apl.aip.org/about/rights_and_permissions

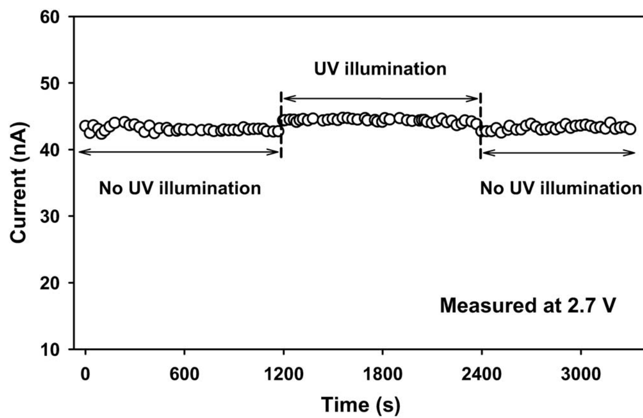


FIG. 2. Time-domain current measurement of one sample that did not exhibit significant conduction instability under UV illumination.

current measurement, the voltage was fixed at 2.7 V. A small voltage was selected to ensure that the measurement itself would not induce charging/discharging in the nc-Al. Indeed, without UV illumination, the *I-V* characteristic within the voltage range was found to remain unchanged during the repeated *I-V* measurements and the current measured during the time-domain current measurement also showed no significant change. This indicates that the current conduction of the nc-Al/AlN thin films was not affected by the measurement itself.

The UV illumination could cause a significant change in the current conduction in some samples, while the phenomenon was not observed in other samples within the time frame of the UV illumination. Figure 2 shows the situation of one sample that did not exhibit significant changes in its current conduction during the time-domain current measurement under the UV illumination (note that the slight increase in the current under UV illumination could be due to the photocurrent generated in the material system). In contrast, Fig. 3 shows large fluctuations in the current conduction of another sample under the UV illumination. For the experiment shown in Fig. 3, the current remains constant before the UV illumination. However, when the UV illumination is applied, the current fluctuates largely. After the UV illumination for the first 205 s, the conductance of the thin film system is switched from a high-conductance state (~42 nA) corresponding to the situation of no or insignificant charge trapping in the nc-Al to a low-conductance state (~3 nA)

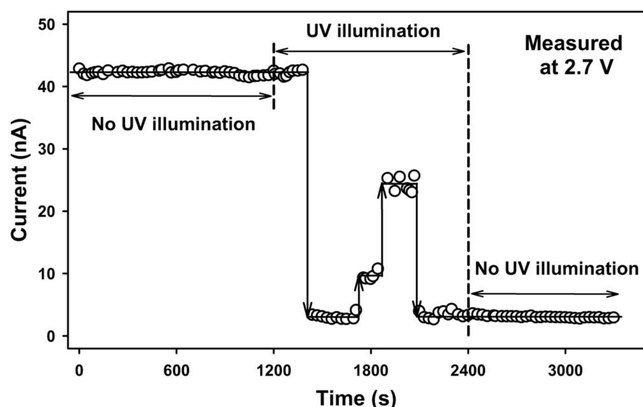


FIG. 3. Time-domain current measurement of another sample showing large conduction fluctuations under UV illumination.

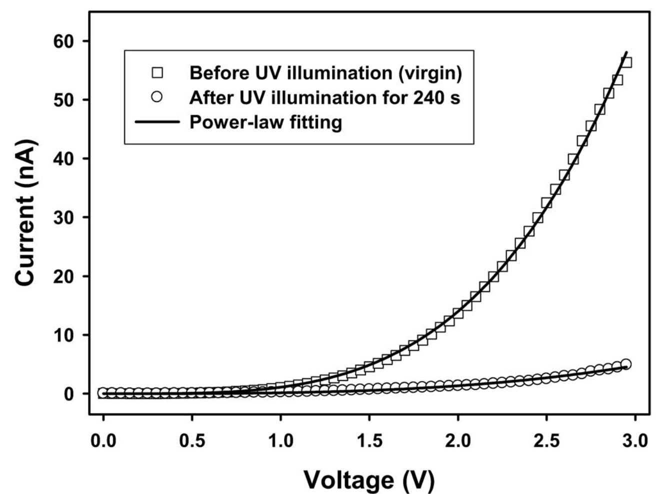


FIG. 4. Influence of UV illumination on *I-V* characteristic of one sample showing the conduction instability.

resulting from the charging in the nc-Al due to the UV illumination. This low-conductance state is maintained for about 320 s and then the conductance is switched to a new state (~9 nA) with a slightly recovered conductance. This indicates that a small amount of the trapped charges in the nc-Al have been released due to the UV illumination and, thus, a partial recovery of the conduction is achieved. The conductance is switched to another higher-conductance state (~24 nA) 145 s later due to further release of the trapped charges in the nc-Al. However, after the UV illumination of 880 s, it is switched back to the first low-conductance state (~3 nA). The conductance switching is a random event reflecting the random nature of the charging and discharging processes.

Significant influence of the UV illumination on the *I-V* characteristic was also observed on some samples. Figure 4 shows the experimental results of one example. As shown in the figure, the current is drastically reduced after the UV illumination for 240 s. The huge reduction in the current indicates a large decrease in the conductance of the thin film system. Other than that, it is observed that the *I-V* characteristics before and after the UV illumination can be described by a power-law relationship

$$I = \alpha_0 (V - V_{th})^{\zeta}, \quad (1)$$

where V_{th} is the threshold voltage and ζ is the scaling exponent. V_{th} is approximately zero for the room-temperature measurement.[12] The power-law behavior can be explained by the model of collective charge transport in arrays of metallic quantum dots separated by tunnel barriers.[13,14] Note that the two parameters, α_0 and ζ are not constant and can vary with samples. The change in the *I-V* characteristic shown in Fig. 4 can be translated to the changes in both α_0 and ζ. The values of α_0 and ζ decrease from 1.11 to 0.16 and from 3.66 to 3.11, respectively, after the UV illumination.

It was experimentally shown that charge trapping in the nc-Al leads to a reduction in the current as well as in both α_0 and ζ.[12] In the study reported in Ref. 12, charge trapping in the nc-Al was realized by applying a large voltage to the metal gate, and the charge trapping was determined from the flatband voltage shift. The current and both α_0 and ζ were found to decrease with the charge trapping. The phenomena were attributed to the increase in the tunneling resistance

Downloaded 16 May 2012 to 147.8.21.150. Redistribution subject to AIP license or copyright; see http://apl.aip.org/about/rights_and_permissions

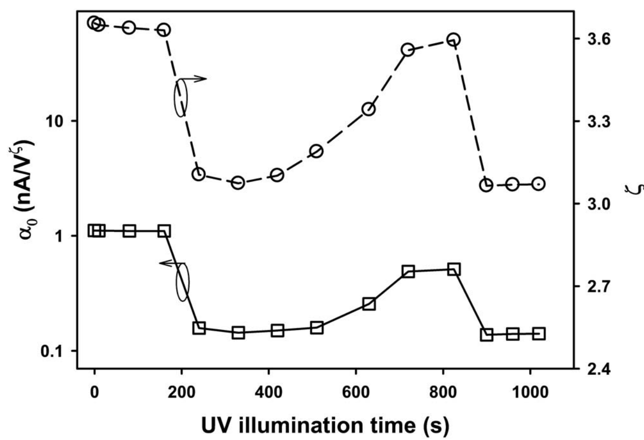


FIG. 5. Fluctuations of α_0 and ζ of one sample showing the conduction instability.

and/or the breaking of some tunneling paths as a result of charge trapping in the nc-Al. The changes in the current as well as in both α_0 and ζ due to the charge trapping in the nc-Al caused by the application of a large bias are very similar to the situation of the UV illumination. Therefore, although we are not able to directly determine the charge trapping caused by the UV illumination due to the difficulty in measuring the flatband voltage with the ITO gate, we believe that the change in the *I-V* characteristic shown in Fig. 4 is due to charge trapping in the nc-Al induced by the UV illumination.

As shown in Fig. 3, for the time-domain current measurement under UV illumination, the UV illumination could cause either a reduction or an increase in the current. This means that UV illumination could cause either charging or discharging in the nc-Al. The phenomenon was also observed in the *I-V* measurement under UV illumination. Figure 5 shows the fluctuations of α_0 and ζ under a constant UV illumination. The fluctuations of α_0 and ζ again reflect the random nature of the charging and discharging processes in the nc-Al.

In conclusion, current conduction of the nc-Al/AlN thin films under UV illumination has been studied. Some samples exhibit random fluctuations in the current conduction under the UV illumination while the others are insensitive to the UV illumination. The conduction instability is due to the charging and discharging in the nc-Al induced by the UV illumination. The charging and discharging in the nc-Al are two competing processes which occur simultaneously and randomly under UV illumination. The conductance of the thin film system is determined by the dominant one of the two competing processes.

This work has been financially supported by the Ministry of Education, Singapore under Project No. ARC 1/04.

[1] P. Kirsch, M. B. Assouar, O. Elmazria, V. Mortet, and P. Alnot, Appl. Phys. Lett. **88**, 223504 (2006).
[2] Y. Taniyasu, M. Kasu, and T. Makimoto, Nature (London) **441**, 325 (2006).
[3] A. T. Sowers, J. A. Christman, M. D. Bremser, B. L. Ward, R. F. Davis, and R. J. Nemanich, Appl. Phys. Lett. **71**, 2289 (1997).
[4] H.-W. Zan, K.-H. Yen, P.-K. Liu, K.-H. Ku, C.-H. Chen, and J. Hwang, Org. Electron. **8**, 450 (2007).
[5] Y. J. Lee, J. Cryst. Growth **266**, 568 (2004).
[6] Y. Liu, T. P. Chen, P. Zhao, S. Zhang, S. Fung, and Y. Q. Fu, Appl. Phys. Lett. **87**, 033112 (2005).
[7] L. Ding, T. P. Chen, M. Yang, J. I. Wong, Y. Liu, S. F. Yu, F. R. Zhu, M. C. Tan, S. Fung, C. H. Tung, and A. D. Trigg, Appl. Phys. Lett. **90**, 103102 (2007).
[8] J. Q. Hu, J. S. Pan, F. R. Zhu, and H. Gong, J. Appl. Phys. **95**, 6273 (2004).
[9] S.-H. Choi and R. G. Elliman, Appl. Phys. Lett. **75**, 968 (1999).
[10] C. Y. Ng, Y. Liu, T. P. Chen, and M. S. Tse, Smart Mater. Struct. **15**, S43 (2006).
[11] Q. Wan, N. L. Zhang, W. L. Liu, C. L. Lin, and T. H. Wang, Appl. Phys. Lett. **83**, 138 (2003).
[12] Y. Liu, T. P. Chen, H. W. Lau, J. I. Wong, L. Ding, S. Zhang, and S. Fung, Appl. Phys. Lett. **89**, 123101 (2006).
[13] A. A. Middleton and N. S. Wingreen, Phys. Rev. Lett. **71**, 3198 (1993).
[14] H. E. Romero and M. Drndic, Phys. Rev. Lett. **95**, 156801 (2005).

Downloaded 16 May 2012 to 147.8.21.150. Redistribution subject to AIP license or copyright; see http://apl.aip.org/about/rights_and_permissions