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# A comparative study of the electrical characteristics of metal-semiconductor-metal (MSM) photodiodes based on GaN grown on silicon

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**Abstract**

We report on the characteristics of metal-semiconductor-metal (MSM) photodiodes based on GaN films grown on silicon substrates by electron cyclotron resonance (ECR) plasma-assisted metalorganic chemical vapor deposition (PA-MOCVD) at growth temperature of 200 and 600 °C. Structural analysis of the GaN samples used for the photodiodes fabrication were performed by using X-ray diffraction (XRD), atomic force microscopy (AFM), scanning electron microscopy (SEM), and energy dispersive X-ray analysis (EDX) to analyze the crystalline quality of the samples. The analysis has revealed that the GaN samples grown at 200 and 600 °C were in amorphous and microcrystalline phase, respectively. Electrical characterization of the MSM photodiodes were carried out by using current–voltage (*I–V*) measurements. At 10 V, the photodiodes based on amorphous GaN has a dark current of 0.18 μA while the microcrystalline GaN based photodiode has a dark current of 18 μA.


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## 1. Introduction

Galium nitride (GaN), a wide and direct band gap semiconductor is a vastly studied semiconductor material due to its potential as an excellent candidate for the application in optoelectronic and high power/temperature electronic devices [1]. Great attention have been received in recent years for the development of visible-blind ultraviolet (UV) photodetectors based on III–V nitride which have application in both civil and military industries such as engine control, flame sensing, source calibration, solar UV monitoring, UV astronomy, secure space-to-space communications, and missile plume detection [2].

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High quality GaN films are usually produced at high growth temperatures (>1000 °C) with the use of substrates such as sapphire ($Al_2O_3$) or silicon carbide (SiC). Therefore, for a low production cost purpose, there has been a growing interest in producing lower growth temperatures GaN films as well as GaN based devices with low cost substrates such as silicon. Growth of GaN onto silicon substrates offers a very attractive opportunity to incorporate GaN devices onto silicon-based integrated circuits.

GaN grown on silicon (Si) based photodetectors are still very few especially of those grown at low temperatures due to the large quantities of defect densities which is attributed to the high lattice and thermal mismatch of Si and GaN. Therefore more work has to be done to investigate its significance for the application in device fabrication as GaN films grown on Si is expected to be an excellent candidate for the integration of GaN-based optoelectronic devices with Si-based electronic technology [3]. Moreover the advantage of low temperature grown films is the capability to deposit the material inexpensively over large areas, which could open up opportunities for the development of low cost and large-area devices such as UV detector arrays.

Photodetectors in the form of metal-semiconductor-metal (MSM) structure are subjected to keen interest among various kind of detectors due to its many attractive features like the ease of fabrication, low dark current, large bandwidth, small capacitance, and the suitability for integration in an optical receiver [4]. Moreover, photodetectors based on low temperature grown GaN especially amorphous GaN which is grown at 200 °C are still very few and further investigations have to be carried out to determine its significance in photodetector application, most probably in UV detector arrays.

In this paper, we report on the comparative study of the electrical characteristics of the MSM photodiodes based on ECR PA-MOCVD grown GaN at growth temperatures of 200 and 600 °C. Structural analysis of the GaN samples used for the photodiodes fabrication were also carried out by using X-ray diffraction (XRD), atomic force microscopy (AFM), scanning electron microscopy (SEM), and energy dispersive X-ray analysis (EDX) to analyze its crystalline quality.

## 2. Experimental

GaN films grown on Si(1 0 0) at 200 and 600 °C by ECR PA-MOCVD were used for this study. Both GaN films are n-type with donor concentrations of about $4.06 \times 10^{13}$ and $1.48 \times 10^{13}$ $cm^{-3}$ for the GaN films grown at 200 and 600 °C, respectively. Details of the reactor and growth technique have been described elsewhere [5].

The structure of the MSM photodiodes consist of two interdigitated Schottky contact (electrode) with fingers width of 230 μm, finger spacing of 400 μm, and the length of each electrode was about 3300 μm. It consists of four fingers at each electrode.

X-ray diffraction (XRD) was used to assess the structure of the deposited layers. These data were collected on a Rigaku diffractometer with a wide angle automated goniometer and computer based data acquisition and analysis system. Scanning electron microscopy (SEM), atomic force microscopy (AFM), and energy dispersive X-ray analysis (EDX) were used to observe the surface morphology and to identify the elements present in the samples.

Nickel (Ni) Schottky contacts were deposited on the GaN samples by thermal evaporation where the pattern of metallization was defined by using a metal mask. Prior to metal contact deposition, the GaN sample which was grown at 600 °C was cleaned in boiling aqua regia ($HCl:HNO_3 = 3:1$) as a way to etch away surface contaminants and native oxides. Then it was followed by thermal annealing at 400 °C in flowing nitrogen environment for 10 min. As the existence of a thin contamination layer cannot be totally ruled out upon cleaning unless the samples are cleaved in an ultra-high vacuum condition [6], thus annealing the Ni–GaN at 400 °C in flowing nitrogen environment for 10 min was done as a way to remove the contamination layer from the GaN/Ni interface [7] and also to reduce the leakage current, increase the Schottky barrier height, and to improve the uniformity of the barrier height [8]. For the GaN sample grown at 200 °C, the method of cleaning prior to contact deposition was the same but the aqua regia solution was not at its boiling point, instead it was at room temperature. The sample was soaked inside the aqua regia solution for about 1 min. The reason for the slight differences in cleaning treatment was mainly due to the amorphous like structure of the sample