Atomic Layer Deposition for GaN Power Semiconductors

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Abstract

Atomic layer deposition (ALD) is considered for deposition of different materials in power semiconductors, due to its excellent growth control and ability to grow high-quality material at relatively low temperatures. In this contribution several relevant ALD processes and surface treatments using Oxford Instruments equipment will be reported. Relevant plasma aspects will also be highlighted.

INTRODUCTION

Atomic layer deposition (ALD) is considered for deposition of different materials in power semiconductors, due to its excellent growth control and ability to grow high-quality material at relatively low temperatures. Several materials can be considered such as Al_2O_3, $HfAlO_x$, AlN, SiN_x, and even GaN itself. One of the key issues is achieving low defect densities at the interfaces of these materials in the device, for instance in a structure as in Fig. 1. The shown recessed gate structure which allows control over the threshold voltage furthermore requires that the deposition is conformal. In this contribution several relevant ALD processes and surface treatments using Oxford Instruments equipment will be reported. Relevant plasma aspects will also be highlighted.

ALD FOR GAN DEVICES AND IN SITU TREATMENTS

To achieve a low defect density at the interface of GaN and the gate dielectric, a variety of surface treatments and cleans are considered. One possibility of doing surface treatments would be doing the treatment in situ, in the ALD tool itself (Fig. 2). This could be one of the known plasma surface treatments (e.g., H_2, N_2, NH_3 plasma). Another effect that can be used is the self-cleaning effect of $Al(CH_3)_3$ (TMA), which is the typical ALD precursor for Al_2O_3. TMA is a reducing agent which can for instance reduce some compound semiconductor oxides, while forming Al_2O_3. Recently, Kerr et al. reported a combined approach using an Oxford Instruments FlexAL® ALD reactor [1]. In their work they demonstrated that doing H_2 plasma exposures alternated by TMA exposures as a pretreatment resulted in low defect density (D_{it}) values. For InGaAs devices, pulses of TDMAT ($Ti(NMe_2)_4$) have been employed as a pretreatment [2]. A similar approach might work for GaN devices in order to have a higher-k interface layer (e.g., have high-k TiO_x at the interface instead of AlO_x which is obtained after TMA pulses). In general a wide range of ALD precursors could be of interest as a pretreatment to clean-up the native oxide on III-V materials [3].

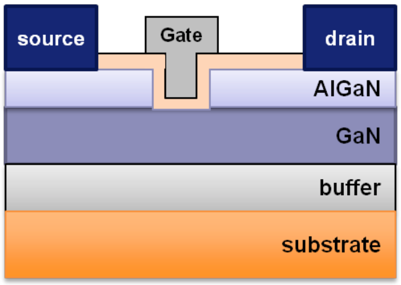

Fig. 1. A schematic cross-section of an AlGaN/GaN metal-oxide-semiconductor high-electron-mobility transistor (MOS-HEMT) with a recessed-gate geometry and conformal gate dielectric. Due to the structure of the recessed gate, conformal deposition processes such as ALD are desired. The sensitive interfaces furthermore require low-damage processes, which thermal ALD and certain plasma ALD processes can provide.

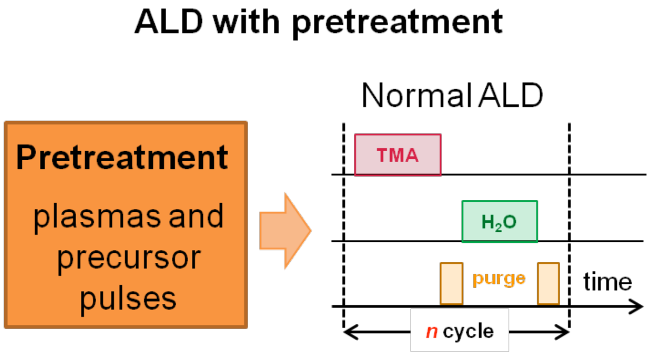

Fig. 2. Besides the capability to run ALD processes, an ALD tool can be used to run a variety of treatments. For instance pulses of plasma and precursor before an ALD process can be used to clean and condition a surface for low defect density and effective ALD nucleation.

Another approach is the growing of ALD nitride interface layers such as reported by Liu et al. using an Oxford Instruments OpAL® reactor [4, 5]. In their work they demonstrated epitaxial growth of 4 nm AlN on GaN on which they deposited 10 nm ALD Al_2O_3 resulting in a dielectric stack with excellent device performance. Similarly, N_2 plasma can be used to create a thin nitride interlayer [6, 7]. These and other approaches will be discussed. Also the ALD of GaN itself will be discussed. GaN with relatively low impurity values was obtained as can be seen in Fig. 3, where it was found that the plasma parameters were most important. Such ALD GaN processes could be relevant for future GaN device structures.

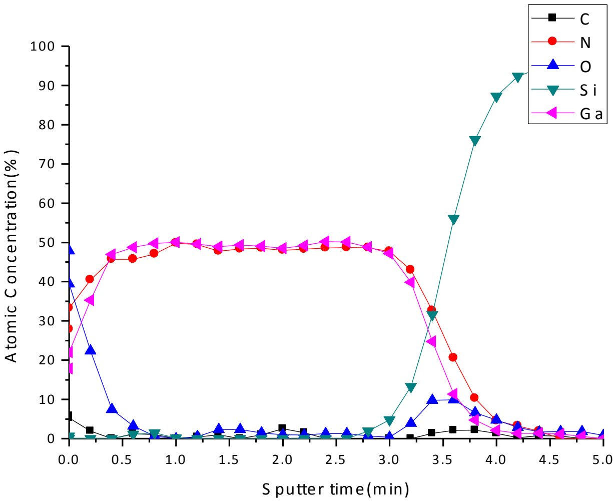

Fig. 3. An AES depth profile of ALD GaN film. Close to stoichiometric GaN was obtained using 350 °C table temperature, and an ALD cycle using triethyl gallium (TEGa) and 10 s H_2/N_2 plasma (30:10) at 400W power at 5 mTorr gas pressure.

Generally the effect of the plasma on the surface can depend on the composition and characteristics of the plasma. O_2 plasmas are known to be able to oxidize GaN and adversely affect the threshold voltage [8]. Methods to control ion energy and UV photon flux during plasma ALD will be discussed (see Fig. 4) as these can also be important to obtain low damage conditions [9, 10]. Generally, varying pressure and plasma power in an ICP plasma allows the minimization of the ion energy and flux. Note, that ion energies of ~20 eV need not negatively affect device performance. For instance the H_2 plasma pretreatments performed by Kerr et al. [1], led to low defect densities while the plasma power of 100 W and plasma pressure of 20 mTorr indicate such ion energies.

CONCLUSIONS

As demands on power semiconductors become more stringent, deposition techniques with control at the nanoscale such as ALD will become required. Plasma ALD has the potential to provide ALD film growth and interface treatments needed to avoid or repair damage. For GaN devices, thermal ALD of Al_2O_3 and plasma ALD of AlN have already been used to achieve low defect densities. In general controlled plasma and ALD precursor exposures can be used to tune III-V interfaces and obtain high-quality devices.

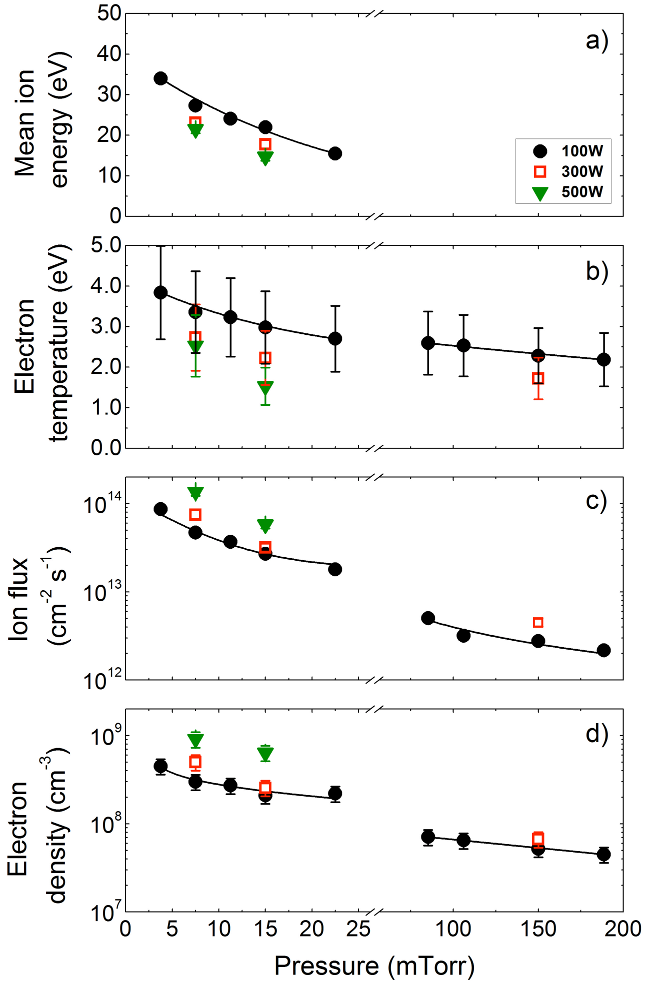

Fig. 4. Pressure and power dependence of (a) the mean ion energy, (b) the electron temperature, (c) the ion flux, and (d) the electron density in an O_2 plasma used for plasma-assisted ALD as measured by Profijt et al. [9]. For ≤ 22.5 mTorr, measurements were performed in the FlexAL® reactor, whereas for p ≥ 85 mTorr, measurements were carried out in the OpAL®. Lines serve as a guide to the eye.

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ACRONYMS

ALD: Atomic Layer Deposition
MOS-HEMT: Metal-Oxide-Semiconductor High-Electron-Mobility Transistor
TMA: TriMethyl Aluminum
TDMAT: Tetrakis (dimethylamino) Titanium
TEGa: TriEthyl Gallium
AES: Auger Electron Spectroscopy
ICP: Inductively Coupled Plasma