GaN Thin Film Gas Sensors

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GaN-based materials are very promising not only for high power and high temperature electronic devices but also for blue and green light emitters, since they have a wide bandgap energy, high breakdown electric field, high thermochemical stability, and high electron saturation velocity. Nitride semiconductors with a wurtzite crystal structure are known to have a direct transition energy gap range from 1.9 eV (InN) to 6.2eV (AlN).[1-2] They also exhibit strong lattice polarization effects which have been recognized as suitable for application to high temperature piezoelectronics and pyroelectric sensors.[3] Other device applications using GaN-based materials are currently being investigated by many research groups.

Until now there have been no reports on chemical sensors, in particular gas sensors, that use a single crystalline GaN epitaxial layer, even though many metal-oxide compound semiconductors, such as ZnO, SnO_2, and WO_3, have been extensively investigated and some are now commercially available. The sensing mechanism of these compound semiconductors is related to various defects (oxygen vacancy, metal vacancy, or other defects) cooperating with the sensing species.[4-5]

This report is the first to present the unique alcohol, and possibly hydrocarbon gas, molecule-sensing properties of an undoped bare GaN surface and Pt-coated GaN surface. The sensitivity dependence of the Pt-coating effect was investigated by monitoring the conductivity changes in the GaN thin films when they were exposed to reactive gas molecules.

An undoped GaN thin films were grown by MOCVD (metal organic chemical vapor deposition) on a 2-inch (0001)-oriented sapphire wafer. After the initial cleaning of the sapphire substrates, TMGa and NH_3, as sources of Ga and N, were introduced into the growth chamber using H_2 as the carrier gas. First, a low temperature GaN buffer layer was grown at 500℃ to initiate the nucleation sites on the substrate. 1.5 ㎛-thick undoped GaN thin films were then grown at 1030℃. After growth, the surfaces of some samples were prepared by depositing a very thin Pt layer with a thickness of 30-50Å.

The structure of the GaN gas sensor is shown in Fig. 1. For ohmic contact, Al electrodes was deposited on the front surface of the substrate and Pt for the heater was deposited on the backside. To investigate the sensitivity of the undoped GaN or Pt-coated undoped GaN to alcohol molecules, an apparatus was set up. A voltage detecting method was used to calculate the resistance of the sensor using the following equation (1).

$$R_S = \left(\frac{V_C}{V_{RL}} - 1\right) R_L \qquad (1)$$

where R_S is the resistance of GaN, V_C is the circuit voltage, V_{RL} is the output voltage, and R_L is the load resistance. The sensitivity was defined as $(R_{air}-R_{gas})/R_{air} \times 100$ (%) where R_{gas} and R_{air} are the electrical resistances of a GaN sample in gases to be detected and in air, respectively.

The background doping concentration of the undoped GaN layer as high as 2.4×10^{17}/㎤ whereas their mobility was as low as 70 ㎠/V · sec. These reveals that the epitaxially grown GaN layer have many surface defects, including V_{Ga}(gallium vacancy) or V_N(nitrogen vacancy), originated from the dislocation or other reasons, which deteriorate the electrical properties of the GaN layer and should be eliminated for the fabrication of electronic or optoelectronic devices. However, it is believed that these vacancies caused by the defects may contribute to the reaction of the gas molecules on the undoped GaN surface.

The gas sensing properties of the GaN-based sensors were tested in a chamber containing hydrocarbon (butane and propane), ethyl alcohol, or carbon monoxide. Ethyl alcohol is recognized as a volatile organic compound (VOC), which are known to cause sick-house syndrome and cancer, carbon monoxide is harmful to the human body and butane is extremely explosive when its concentration exceeds a certain critical value[6]. The undoped GaN exhibited the highest sensitivity to ethyl alcohol, approximately 30% at 1000 ppm, and yet a negligibly small sensitivity to the other gases. However, in the case of the Pt-coated GaN thin film, as shown in Fig. 2, the sensitivity to ethyl alcohol was greatly enhanced to 70% at 1000 ppm along with a proportional increase in sensitivity to the other gases. This was because the resistance of the GaN changed due to the reaction between the gas molecules and the crystal defects on the surface. The enhanced sensitivity caused by the Pt coating can be explained as follows. It would appear that the Pt functions as a sorption site for gas molecules on the GaN surface, in addition, the modulation in the space charge region in the Pt-GaN schottky contact due to the reaction with the gas molecules is responsible for a further decrease in the resistance.[5] The time-response of the Pt-coated GaN film is shown in Fig. 3. When exposed to 1000 ppm C_2H_5OH, the resistance of the Pt-coated GaN thin film decreased rapidly from 430 kΩ to 120 kΩ and it also quickly recovered to the baseline when the gases were vented.

The GaN alcohol gas sensor exhibited a good sensitivity, good recovery, selectivity, and fast reaction with alcohol molecules. Furthermore, by modulating the species and quantity of the coating catalysts the sensitivity to gas molecules and combustible gases can be enhanced. Therefore, this paper demonstrated the potential of GaN as chemical sensors, particularly gas sensors.

References

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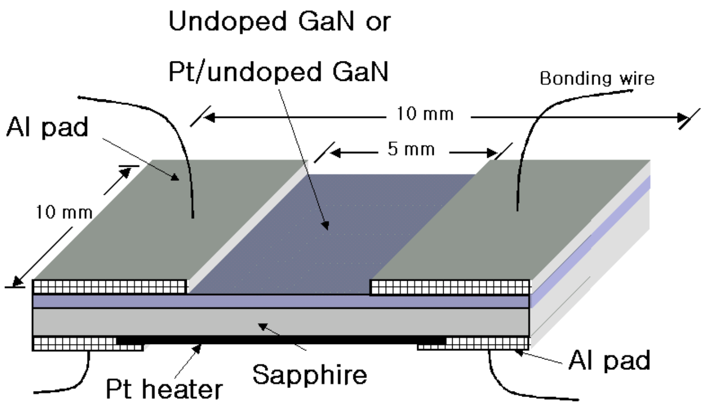

Fig. 1. Structure of a Pt/undoped GaN gas sensor.

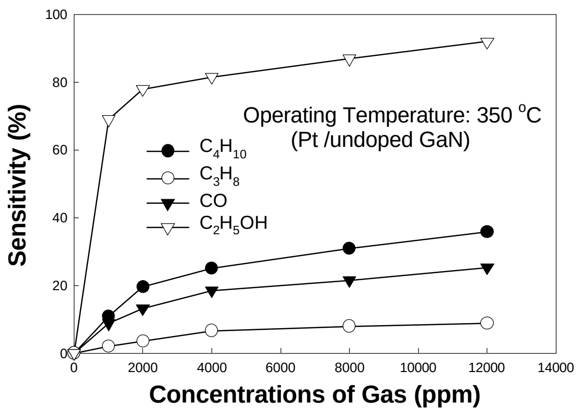

Fig. 2. The sensitivity of a Pt/undoped-GaN thin films as a function of gas concentrations at 350℃.

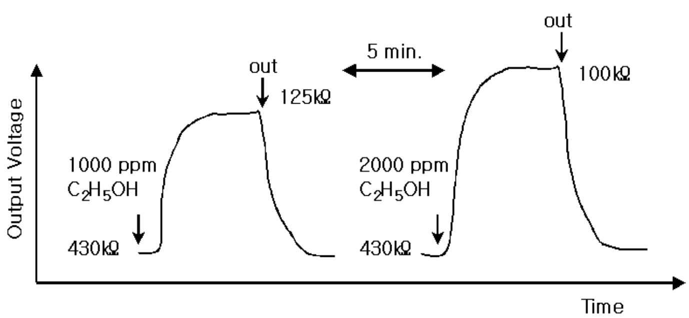

Fig. 3. Time response of Pt-coated an undoped-GaN thin film in injection of alcohol at 350℃.