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A GaN-based two-sensor array for methane detection in an ethanol environment

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Abstract
We demonstrate that photoelectrochemical (PEC) etching of GaN layers in KOH or H_3PO_4 solutions leads to the formation of specific surface morphologies which cause the material to exhibit different sensitivities to certain gases. PEC etching in a KOH solution results in a pyramidal morphology of the layer which exhibits a high sensitivity to methane gas, whereas etching in a H_3PO_4-based solution leads to the formation of individual nanoneedles with a high sensitivity to alcohol vapours. We also investigated the gas sensitivity of GaN structures with different morphologies as a function of temperature and the cross sensitivity to humidity. These results culminated in an integrated two-sensor array for methane detection in environments containing ethanol vapours. A new method of improving the recovery time characteristics of the sensor by applying high-voltage pulses is proposed.

Solid-state gas sensors play an important role in detecting and controlling the chemical processes in the environment, for personal safety [1, 2]. Semiconducting metal oxide sensors have been widely investigated owing to their small dimensions, low cost and high compatibility with microelectronic processing. Most commercial sensors are based on SnO_2 and Ga_2O_3 [3]. However, the commercial success of most metal oxide sensors is limited by disadvantageous properties such as unintended cross sensitivity, drift, changing sensitivity in time, poor reproducibility, and long response and recovery time. It is reasonable, therefore, to examine other and possibly more conducive semiconductors such as large bandgap varieties as potential sources for gas sensors. Large bandgap semiconductors such as diamond or gallium nitride are prime candidates for a variety of sensor applications, particularly those operative at high temperatures and in harsh environments [4–7]. One of the major problems with gas sensors is the cross sensitivity, particularly the cross sensitivity to alcohol in domestic warning systems for methane leakage detection where the alcohol is the most interfering factor. Different approaches have been employed to overcome this problem such as the use of catalytic filters to block interfering and poisoning gas molecules from reaching the sensor surface [8, 9], modulation of the operation temperature producing selectivity due to different thermal energies for surface reactions [10], simultaneous monitoring of several parameters [11] and doping with different elements [12].

The purpose of this paper is to demonstrate the effectiveness of photoelectrochemical etching of GaN for the formation of layers with different morphologies and therefore exhibiting different levels of sensitivity to certain gases and to make use of this approach for methane detection in environments containing ethanol vapours.

The GaN layers used in this work were grown by low-pressure (60–110 Torr) metalorganic chemical-vapour deposition (MOCVD) on (0 0 0 1) *c*-plane sapphire substrates using trimethylgallium and ammonia as source materials [13]. The alkyl and hydride sources were kept separately until just before the quartz reactor. The carrier gas was Pd-cell purified hydrogen (H_2). Heating was accomplished by rf induction of the graphite susceptor. All valves and manifolds