Magneto–electric properties of magnetic field sensors fabricated using AlGaN/GaN heterostructures for harsh environments

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ABSTRACT

Hall effect sensors are ubiquitous, being used in the electronics industry for monitoring rotation in optical memory disks, banknote authentication in vending machines, and for sensing currents in cables. Other notable applications of micro Hall sensors include scanning Hall probe microscopy (SHPM) and medical diagnostics based on the detection of magnetic tags attached to target molecules. Now, while Hall sensors are widely used at cryogenic and ambient temperatures, there are still niche demands for Hall sensors that are stable at elevated temperatures of about 400°C for applications such as the determination of the Curie temperatures of ferromagnetic materials. More recent demands include the sensing of currents in electric cars, where the ambient is well above room temperature. Hall sensors are also promising for space applications such as in electronics systems for space exploration vehicles, where size and power consumption are important, and monitoring magnetic fields in charged particle accelerators. Recently there have been reports on indium antimonide (InSb) based Hall sensor devices as candidates to replace magnetic sensors used in thermonuclear power stations. In such extreme environments Hall sensors must withstand high temperatures and particles and/or electromagnetic irradiation.

Conventional Hall sensors fabricated using silicon (Si), indium arsenide (InAs) or indium antimonide are stable up to temperatures of about 125°C, and above this temperature, the sensors are inoperable due to the onset of intrinsic conduction and physical degradation of the semiconducting materials. Silicon carbide (SiC) could potentially be used for fabricating Hall sensors operating at high temperature because of its large band gap, high electron saturation velocity, and excellent thermal stability at high temperatures. However, the need for precise control of dopants and the large

thickness of the conducting layers of SiC severely limits its sensitivity and stability at high temperatures. The gallium nitride (GaN) and its related compound aluminum gallium nitride (AlGaN) have wide band gap, high thermal and chemical stabilities. The gallium nitride has low intrinsic electron concentration, which is several orders of magnitude lower with respect to that of Si or gallium arsenide (GaAs), and comparable with that of SiC, enabling the increase of the maximum operation temperature. Moreover, gallium nitride has high threshold displacement energy making this material tolerant against particles irradiation; therefore, Hall sensors based on the GaN are suitable for magnetic field sensing for high temperature and high-energy particles irradiation application fields.

In addition, formation of the two–dimensional electron gas at the interface between the AlGaN and GaN gives rise to high electron density in a thin active region of thickness of few nanometers and to high electron mobility, making the AlGaN/GaN heterostructures appropriate for Hall sensor devices. The fabrication and the characterization at high temperature and high proton irradiation of Hall sensors based on the AlGaN/GaN heterostructures were described and compared with the conventional Hall sensors based on AlGaAs/GaAs and AlInSb/InAsSb/AlInSb heterostructures. Electrical characterizations of the micro–Hall sensors based on AlGaN/GaN heterostructures at high temperature and high–energy proton irradiation showed that micro–Hall sensors based on AlGaN/GaN heterostructures are stable from cryogenic temperature to a temperature of 400°C and expected to show stability up to about 700°C, and are tolerant to high–energy proton irradiation up to proton dose of 10^{14} protons/cm^2. Proton irradiation on the AlGaN/GaN heterostructures based micro-Hall sensors induce defects and crystal quality damage, however, the possibility of recovering of the crystal quality and defect removing by annealing was confirmed by electrical and optical characterizations.

The micro-Hall sensors reported in this study were not protected by any form of packaging. The maximum proton fluence at which the AlGaN/GaN heterostructures based micro-Hall sensors are stable at is equivalent to thousands of years of the sensor application lifetime at the low-earth orbit (LEO). However, the protection of the micro–Hall sensors by a ferromagnetic materials can in the same time enhances the sensor sensitivity and detectivity and reduces or stops the effect of proton irradiation, therefore, increases the micro–Hall sensors lifetime in harsh environments.

The AlGaN/GaN heterostructures and the AlInSb/InAsSb/AlInSb quantum wells based micro–Hall sensors are good candidates to replace the magnetic sensors used in the outer space application in term of size, power consumption, and proton irradiation hardness.