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Implantation induced electrical isolation of sulphur doped GaN_xAs_{1-x} layers

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Abstract

The study of III-N-V semiconductor alloys, especially GaN_xAs_{1-x} has been increasing in the last few years. The strong dependence of the band gap on the nitrogen content has made this material important for a variety of applications, including long wavelength optoelectronic devices and high efficiency solar cells. We report on the effects of sulphur doping implants on the achieved electrical isolation in GaN_xAs_{1-x} layers using proton bombardment. Sulphur ions were implanted in MOCVD-grown GaN_xAs_{1-x} layers (1.4 μm thick with nominal $x = 1\%$) with multiple energies creating approximately uniform doping profiles in the range of about 1×10^{18}–5×10^{19} cm^{-3}. Several proton implants were performed in order to find the threshold dose (minimum dose to achieve maximum sheet resistivity) for the electrical isolation of n-type GaN_xAs_{1-x} layers. Results show that the sheet resistance of n-type layers can be increased by about five orders of magnitude by proton implantation and the threshold dose to convert a conductive layer to a highly resistive one depends on the original free carrier concentration. The study of annealing temperature dependence of sheet resistivity in proton-isolated GaN_xAs_{1-x} layers shows that the electrical isolation can be preserved up to 450 and 500 °C when the implantation is performed at RT and 77 K with threshold dose, respectively. These results for n-type GaN_xAs_{1-x} layers are novel and have ramifications for device engineers.

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1. Introduction

The III–V nitride compounds are potential candidates for new generation of light emitters and other optoelectronic devices operating across the

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visible and UV wavelengths, and for high temperature-high power electronics [1]. Incorporation of a few percent of nitrogen (N) into GaAs causes an extraordinary reduction of the bandgap and a modification of the conduction-band structure, which have attracted considerable theoretical and experimental interest [2]. While there have been extensive studies of the materials properties and growth of GaNAs, there has been less emphasis on the implantation characteristics of GaNAs. Implantation induced isolation technology has been recognised for its advantages in high-density IC applications with high throughput and uniformity for III–V devices [3]. An effective and reliable technology for electrical isolation of devices in III–V semiconductors is an essential requirement for the better efficiency of a number of commercial applications. A general advantage of ion implantation induced electrical isolation is the lateral selectivity, preservation of surface planarity [3,4], better reproducibility and less intrusion under the mask edges [5]. Implantation with the right ion species, dose, energy and substrate temperature is important to convert a conductive layer into a highly resistive one or to improve the isolation between devices in integrated circuits [6]. Extensive research has been conducted on implant isolation of GaAs [7], InGaAs [8] and GaN [9] layers. The electrical isolation of p-type GaNAs epilayers produced by H, Li, C and O ion implantation is studied [2] and it is shown that the threshold dose depends on the original carrier concentration and the number of atomic displacements.

Here, we have studied the formation of high resistivity regions produced by proton bombardment in sulphur doped GaNAs layers. The effects of original free carrier concentration, dose, substrate temperature and annealing temperature on the implantation-induced isolation have been quantified by sheet resistance measurements. An annealing window is determined for effective electrical isolation. The data for the evolution of sheet resistivity (R_s) as a function of annealing temperature for sulphur-doped n-type GaNAs layers are reported here for the first time.

2. Experimental

The GaNAs layers were grown on (100)-oriented semi-insulating GaAs substrates in a vertical high-speed rotating-disc MOCVD reactor at temperatures between 500 and 650 °C. Triethylgallium (TEG), tertiary butyl arsine (TBA) and unsymmetric dimethylhydrazine (DMH) were used as precursor compounds. Pure GaAs of 10 nm thickness, which was removed after annealing, capped the nitrogen-containing film. As-grown GaNAs wafers were annealed at 700 °C for 60 s in nitrogen ambient using rapid thermal annealing (RTA) to retain the stoichiometry of the material as well as optical quality. Wafers of GaN_xAs_{1-x} (with nominal $x = 1\%$) films with a thickness up to ~1.4 μm were divided into four groups and implanted with multiple energy sulphur ions to form an approximate flat dopant distribution of $\sim 1\times10^{18}$, 5×10^{18}, 1×10^{19} and 5×10^{19} cm^{-3}. All four groups of wafers were then cleaved to obtain several samples of approximately 1 cm^2 for the preparation of the resistors. The samples were cleaned in organic solvents and the cloverleaf pattern was printed using optical lithography. Etching of the GaNAs samples was done using a solution of 50% hydrochloric acid (HCl). The total etch depth was measured using a Rank Taylor Hobson Talystep, the error typically being 5%. The photoresist was then removed in acetone leaving the cloverleaf pattern on the samples. The samples were implanted with protons (H^+) ions at energy of 250 keV with doses in the range of 5×10^{13}–1×10^{16} ions-cm^{-2}. The substrate temperature during implantation was kept at room temperature (RT). In order to minimise the channelling effects, the sample was tilted by 7° to the surface normal with respect to beam incident direction, with a beam current density <0.2 μA/cm^2.

Post-implant annealing was performed in a rapid thermal annealing furnace in the temperature range from 100 °C to 700 °C (±5 °C) for duration of 60 s in a nitrogen atmosphere. Ohmic contacts of the samples were made by tin (Sn) soldering in a Van der Pauw configuration, alloyed at 235 °C for 2 min in nitrogen ambient. The ohmic behaviour was confirmed by the linear *I*–*V* characteristics.