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Implant isolation of plasma-assisted MBE grown GaInAsN for opto-telecommunication applications

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Abstract

The material system GaInAsN is considered to be one of the key materials for next generation telecommunication applications providing high data transmission and lower power consumption. The strong dependence of the band gap on the nitrogen content has made this material important for a variety of applications. We report on the effects of ion implantation on the achieved electrical isolation in GaInAsN layers. GaInAsN was grown using either a direct nitrogen beam or dispersive nitrogen radicals by a RF activated nitrogen source. Proton and iron implants were performed at RT and 77 K, respectively in order to effectively isolate the as-grown silicon (n-type) GaInAsN layers. Results show that the sheet resistance of n-type layers can be increased by about four and five orders of magnitude by proton and iron implantation, respectively. The study of annealing temperature dependence of sheet resistivity in proton-isolated samples shows that the electrical isolation can be preserved up to 450 °C. The thermally stable high resistivity region persists up to 600 °C when the implantation is performed with iron at 77 K. These results are novel and have ramifications for device engineers.

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Keywords: GaInAsN; Ion implantation; Electrical isolation; Cold implants; III-N-V; Plasma-assisted MBE

1. Introduction

The unique electronic properties of GaInAsN make it an attractive material for use in data communication lasers and high-efficiency multijunction solar cells [1]. The merits of this material are

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due to the strong bowing in the band gap of the GaAs–GaN alloy system, which enables the extension of the spectral range of light emitted from GaAs-based structures to 1.3 μm and longer. At the same time, the band-offsets between InGaAsN and GaAs exceed those in the commonly used InGaAsP system, which must markedly improve the high-temperature performance of 1.3 μm lasers [2]. Combination with the presently available GaAs/AlAs distributed Bragg reflector (DBR) technology could also give novel vertical-cavity lasers for the long wavelength region [2]. While there have been extensive studies of the materials properties and growth of GaInAsN, there has been less emphasis on the implantation characteristics of GaInAsN. 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 semi-conductors 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 n-type InP and InGaAs layers. High thermally stable isolation ($\sim 10^7\ \Omega/\square$) in n-type InP was reported by implantation of He^+, B^+ and N^+ [7–9]. No suitable implant isolation recipes exist for n-type GaInAsN-based devices [10]. These devices are of particular technological importance because of their use in opto-telecommunication systems.

Here, we have studied the formation of high resistivity regions produced by protons and iron ion bombardment in n-type GaInAsN layers. The effects of substrate temperature and annealing temperature 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 iron-implanted n-type GaInAsN layers maintained at 77 K and RT are reported here for the first time.

2. Experimental

The GaInAsN layers were grown in a solid source molecular beam epitaxy system, equipped with five standard effusion cells for gallium, aluminium, indium, beryllium and silicon, three cracker cells for arsenic, phosphorous and hydrogen, and one plasma source for nitrogen. 0.5 μm thick n-type (silicon-doped) GaInAsN samples were grown on (1 0 0)-oriented semi-insulating GaAs substrates prepared using standard procedures. The beam equivalent pressures for Ga and As were 4.6×10^{-7} Torr and 6×10^{-6} Torr, respectively. The V/III ratio was fixed at about 35 for the growth of all samples. The nitrogen plasma source works at nitrogen background pressure of 3×10^{-6} Torr in the presence of As_4 (6×10^{-6} Torr) and is activated by radio frequency power greater than 60 W to maintain the plasma in high brightness mode. The wafers were cleaved to obtain several samples of approximately 1 cm^2 for the preparation of the resistors. All samples were cleaned in organic solvents and the cloverleaf pattern was printed using optical lithography. Etching of the GaInAsN samples was done using a solution of sulphuric acid (H_2SO_4), hydrogen peroxide (H_2O_2) and water (H_2O) in the ratio of 1:1:10. 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 then divided into two different groups and named as A and B. The group A n-type GaInAsN samples were implanted with protons (H^+) ions at energy of 200 keV with 5×10^{13} ions-cm^{-2}. The group B samples received a dose of 2×10^{12} cm^{-2}at a single energy of 2 MeV iron (Fe^+) ions. The substrate temperature during implantation was kept at room temperature (RT) and 77 K for both groups. For 77 K implants, the samples were mounted on a cold stage, which was cooled using liquid nitrogen. In order to minimize channelling effects, the sample was tilted by