Ion implantation for semiconductor lasers

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***Abstract*— Ion implantation for the electrical isolation of semiconductor lasers is a commonly applied technique for multi-quantum well (MQW) lasers, as well as for the deep electrical isolation for quantum cascade lasers. In this paper, we present in detail the theoretical simulations of ion implantation processes for deep electrical isolation of AlGaAs/GaAs quantum cascade and for vertical-cavity surface-emitting laser structures. It will be shown the planning steps for establishing the optimal conditions for the proton implantation processes, which led to the choice of the ion energy and type of masking layer. They employed the simulations of distributions of implanted protons and vacancies, formed after the irradiation into the semiconductors as GaAs, AlGaAs etc. and different types of masking layers. The profiles were calculated from the data simulated by the TRansport in Matter code. It will be presented the design process and verification of scheme for AlGaAs/GaAs quantum cascade and vertical-cavity surface-emitting laser structures.**

Keywords—hydrogen implantation, TRIM code, vacancies

I. INTRODUCTION

Ion implantation in III-V compounds is commonly used in fabrication of semiconductor devices and integrated circuits (ICs) [1-3]. Usually it is employed for dopant introduction and for electrical isolation, called implantation-isolation. In the second one defects produced act as traps for carriers converting the conducting regions into highly resistive ones. Ion implantation for the electrical isolation of semiconductor lasers is a commonly applied technique for multi-quantum well (MQW) lasers, as well as for the deep (below the epitaxial surface) electrical isolation for quantum cascade lasers (QCLs). This technique enables us to design highly resistive regions within semiconductor lasers due to the trapping of charge carriers on deep defect centers, which we can attribute to the lattice disorder produced by the implanted ions when they impinge into the semiconductor. In this work, we focus on the ion implantation process for quantum cascade lasers (QCLs) and vertical-cavity surface-emitting laser (VCSEL) structures. We show our theoretical predictions of the ion implantation process as well as the experimental results.

II. THEORETICAL PREDICTIONS OF THE ION IMPLANTATION PROCESS

The ion implantation process can be used for electrical isolation and for the electrical current aperture formation in VCSELs. For the purpose of calculations, the structure was simplified using the virtual crystal approximation. Depth profiles of concentration of implanted ion and vacancies created were calculated using the Transport of Ions in Matter (TRIM). For the formation of a current aperture in VCSELs the simulations were carefully planned so that the resistive regions would end just above the active region. Moreover, a difficult requirement to meet was to assure the high electrical conductivity of the surface layer (the cap layer) in a VCSEL structure. This can be achieved with hydrogen (proton) implantation, as the difference of vacancies produced at the maximum depth and at the surface is greatest for all implanted ion species. The maximum of vacancy concentration, and thus the electrical isolation, can be precisely controlled by choosing the right implant energy – see Fig. 1 for profiles for several energies.

We calculated the longitudinal (depth) and lateral distributions of hydrogen and vacancies for the implantation with H+ ions into the VCSELs and QCLs. During calculations it was accounted for the standard 7° angle between the beam direction and the sample. Therefore the lateral distributions are slightly shifted. Because of defects introduced during implantation processes can lead to unintentional lateral isolation, which can impact on the parameters of final devices it was necessary to develop of algorithm for calculating the maps of vacancies [4].

For deep, above 6 microns in depth, proton implantation processes which are necessary for QCLs, theoretical predictions were focused on the choosing proper doses and energies from 540 keV to 740 keV. It was simulated influence of these parameters on the distribution of vacancies. It was taking into account the impact of the parameters of implantation processes on different masking layers.

In order to explain the proton implantation scheme on modal characteristics and optical confinement, it was performed theoretical calculations. For QCLs, it was applied a 2D effective index method [5] combined with a 2D electrothermal time-dependent model [6] which takes into account the evolution of the temperature distribution within the electrical pulse. It will be presented the distributions of the optical modes of the mesa design and proton-implanted design in the plane of the laser facets.

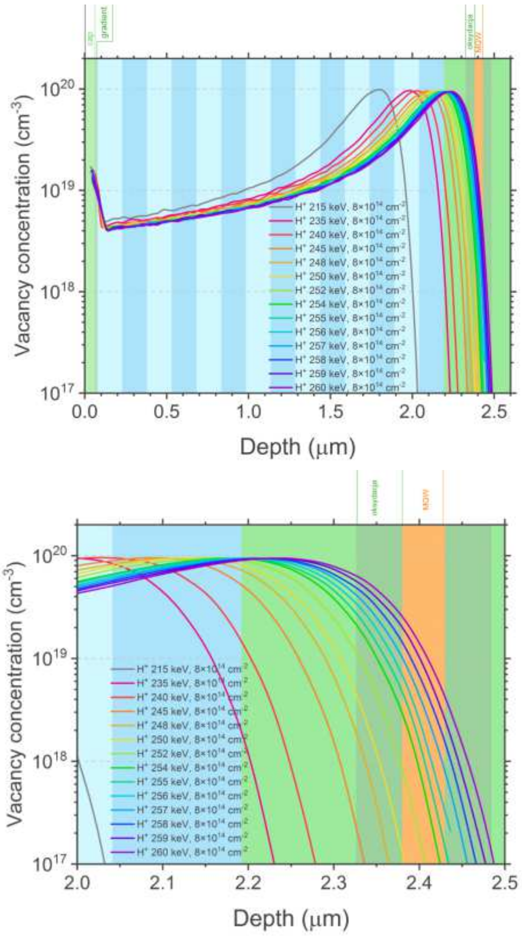

Fig. 1. Vacancy concentration depth profiles, for the hydrogen (proton) implantation into a VCSEL structure.

It will be shown in detail the designing of hydrogen implant isolation scheme, alongside with experimental verification.The experiments were carried out on VCSEL epitaxial test samples and QCL structures to verify the fabricated electrical isolation by proton implantation, establish the optimal implantation dose, and determine the thermal stability of the isolation.

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