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Radiation hardness studies of VCSELs and PINs for the opto-links of the Atlas SemiConductor Tracker

M.L. Chu[a], S. Hou[a,*], T. Huffman[b], C. Issever[b], S.C. Lee[a], R.S. Lu[a], D.S. Su[a], P.K. Teng[a], A.R. Weidberg[b]

[a] *Institute of Physics, Academia Sinica, Taipei, Taiwan*
[b] *Department of Physics, Oxford University, Oxford, UK*

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Abstract

We study the radiation hardness of the Vertical Cavity Surface Emitting Laser diodes (VCSELs) and the epitaxial silicon PIN diodes that will be used for the Atlas SemiConductor Tracker at the CERN Large Hadron Collider. The tests were conducted with 200 MeV protons to a fluence of $4\times10^{14}\,p/cm^2$ and with 20 MeV (average energy) neutrons to $7.7\times10^{14}\,n/cm^2$. The radiation damage of the VCSELs and PINs and the annealing characteristics are presented.

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1. Introduction

The SemiConductor Tracker (SCT) of the Atlas detector at LHC will consist of 6.2 M channels of silicon micro strips [1]. Optical links will be used for receiving the Timing, Trigger and Control (TTC) data, and for data transmission at 40 Mbit/s from the detector modules to the off-detector electronics [2,3]. The opto-package is illustrated in Fig. 1. It consists of two Vertical Cavity Surface Emitting Laser diodes (VCSELs) emitting light around 850 nm and an epitaxial silicon PIN diode.

The radiation damage expected for the SCT opto-electronics is caused by the high flux of charged particles and low energy neutrons in the Atlas experiment. The predicted fluences over a 10-year operating life are 2×10^{14} neutrons and 1.5×10^{14} charged-hadrons per cm^2 [1]. Applying the NIEL scaling [4] and a safety factor of 1.5, the radiation tolerance is required for the equivalence of 1 MeV neutrons of $2\times10^{14}\,n/cm^2$ for silicon devices (the PIN diodes), and $1\times10^{15}\,n/cm^2$ for GaAs devices (the VCSELs).

In previous studies the VCSELs and PINs were exposed to gamma to a total dose of 600 KGy, and to 30 MeV protons to a fluence of $2\times10^{14}\,p/cm^2$ [5,6]. In this report we present studies with 200 MeV protons at the Indiana University Cyclotron Facility (IUCF), and with neutrons of an average energy of 20 MeV at the Cyclotron Research Centre (CRC), Louvain-la-Neuve, Belgium. The samples include two types of VCSELs used in SCT,[1] and epitaxial silicon PINs of two manufacturers.[2]

2. Radiation damage to VCSELs

The VCSELs are made from a GaAlAs multi-quantum well structures. The radiation is expected to cause atomic displacement damage by nuclear interactions. The defects

*Corresponding author.
E-mail address: suen@phys.sinica.edu.tw (S. Hou).

[1] The proton-implant VCSEL (TSD-8A12) is used on the SCT opto-package, and the oxide-confined VCSEL array (TSA-8B12, 12 channel) is used on off-detector readout module. The manufacturer is Truelight, Taiwan.

[2] AEPX-10 of Centronic, UK, and TPD-8D12 of Truelight, Taiwan. TPD-8D12 is used in SCT.

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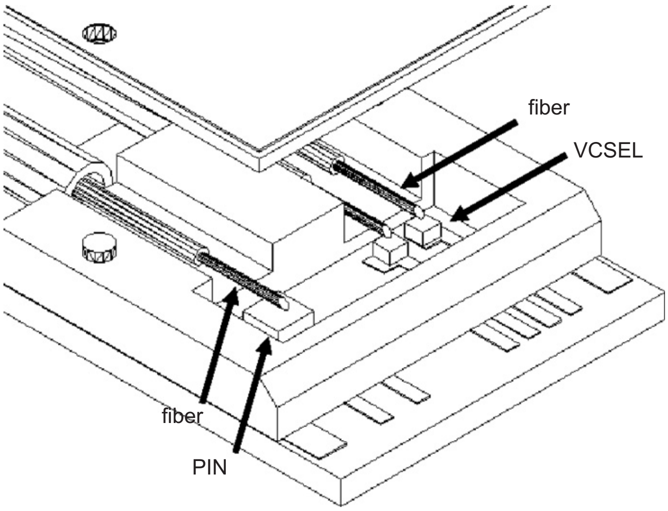

Fig. 1. A schematic drawing of the SCT opto-package.

can act as non-radiative recombination centers, which decreases the minority carrier lifetime and results to increase in laser threshold current. However, most of this damage can be removed by injection annealing.

The VCSELs in use by SCT are of two fabrication technology applying proton-implant or oxide-confined layer for current confinement. The test samples for irradiation were prepared in arrays of bare die VCSELs bonded on circuit board. The laser optical power (L) as a function of the drive current (I) was measured by a large area germanium photo-diode.[3] The L–I distributions of channels of a proton-implant VCSEL array and of an oxide-confined VCSEL array taken before irradiation are shown in Fig. 2. The annealing of VCSELs is a fast process with the normal operating current applied. In order to study the time dependence of annealing, some of the VCSELs were not biased during irradiation. The temperature dependence was also examined. The error caused by deviation in room temperature is within 2%.

2.1. Radiation damage with 200 MeV protons

The radiation tests at IUCF were conducted with 200 MeV protons at a flux rate of about 3×10^{14} p/cm^2 s with an uniform beam profile of about 3 cm in diameter. In one of the test setups, the VCSEL optical power was measured during irradiation. The laser light was transmitted by Fujikura ribbon fibers[4] out of the beam area. The $L-I$ curves observed for an oxide-confined VCSEL channel are plotted in Fig. 3. Each $L-I$ curve is fitted to a linear function. The distributions of the optical power at 10 mA, threshold current, and slope (Fig. 3b–d, respectively) show a linear degradation to fluence.

[3]GM10HS, 10×10 mm^2, GPD Optoelectronics Corp.

[4]The Fujikura S-12T-40/50/125-R fiber is investigated for radiation hardness [7].

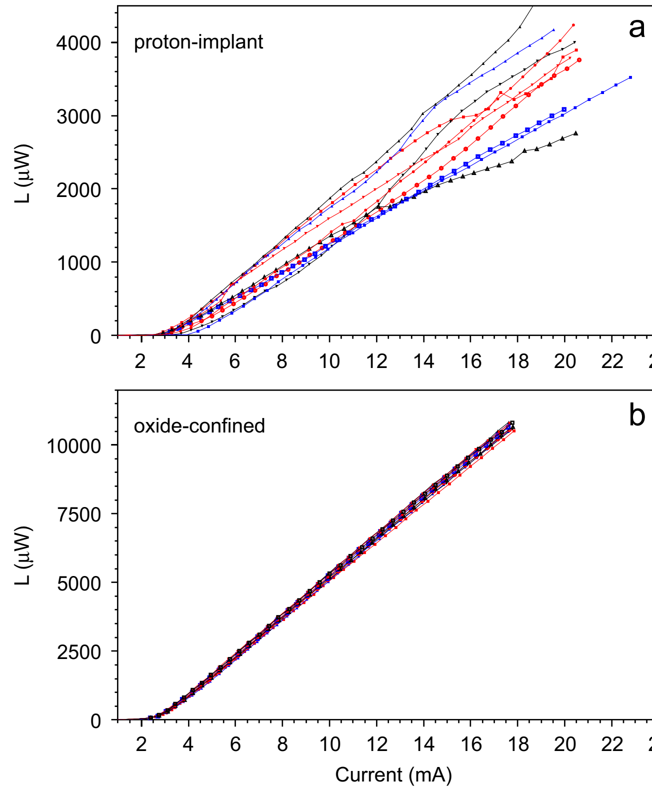

Fig. 2. Optical power versus current of channels of a typical (a) proton-implant, (b) oxide-confined VCSEL array.

The radiation hardness of the two types of VCSELs was compared in a test setup with arrays of each type mounted in parallel on a test board for irradiation. The VCSELs were biased at 10 mA during irradiation to the desired fluences at a rate of 1×10^{14} p/cm^2 per hour. The distributions shown in Fig. 4 are the increase in threshold current versus the degradation of optical power and slope of the $L-I$ curve. The proton-implant VCSELs (10-channel arrays) show a large fluctuation in $L-I$ distributions, while those of the oxide-confined VCSELs (12-channel arrays) are uniform and the degradation rates are consistent between channels. These measurements are summarized in Fig. 5 for the corresponding proton fluence. Each data point is the average of channels of a VCSEL array. The radiation damage to the two types of VCSELs are compatible. The VCSEL arrays irradiated with 4×10^{14} (200 MeV) p/cm^2 had the threshold current increased by about 1.5 mA, and the optical power at 10 mA degraded by about 30%. The systematic error is estimated to be 3% for deviation in sample preparation, alignment of optical power measurement, and temperature.

The annealing was conducted for the oxide-confined VCSELs with half the channels of an array kept at 6 mA, and the rest at 10 mA. The $L-I$ parameters measured during annealing for channels irradiated with 4×10^{14} (200 MeV) p/cm^2 are plotted in Fig. 6. Channels biased at 10 mA show a faster recovery. After 80 h of annealing, the recovery corresponds a threshold current of about 0.7 mA