SURFACE PASSIVATION OF INFRARED LASER DIODE AND PHOTODIODE

By

Ashonita Chavan

An Abstract of a Thesis Submitted to the Graduate
Faculty of Rensselaer Polytechnic Institute
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
Major Subject: Electrical Engineering
The original of the complete thesis is on file
in the Rensselaer Polytechnic Institute Library

Examining Committee:

Dr. Partha Dutta, Thesis Adviser
Dr. Yannick Le Coz , Member
Dr. Zhaoran Huang, Member
Dr. Omkaram Nalamasu, Member

Rensselaer Polytechnic Institute
Troy, New York

March 2006
(For Graduation May 2006)

ABSTRACT

III-V semiconductor compounds are interesting candidates for a variety of optoelectronic applications. However, these semiconductors suffer from poor surface properties leading to device degradation. As the surface is chemically unstable, it leads to formation of native oxide on the surface with time and exposure to atmosphere. The oxide semiconductor interface has high density of interface states, dangling bonds and defects, which lead to facet degradation in case of laser diodes and surface leakage current in case of photodiodes. Thus treatment of surface by removal of oxide and passivation is imperative to improve the performance of the device.

The goal of this research was to study the effect of passivation on two important optoelectronic devices namely, high power infrared laser diodes and infrared photo detectors. A method for estimating the temperature at the facet of a 940 nm Al-free ridge-waveguide InGaAsP-GaAs high power laser diode has been developed. This is based on correlating the change in cladding layer photoluminescence wavelength due to the operation of the device to the wavelength change by external heating. Facet temperatures of unpassivated, unpumped and passivated devices were compared to the bulk temperature. The results indicate that the facet temperature of unpassivated devices were 20 °C - 30 °C hotter than the device bulk temperature whereas the facets of passivated devices were only 10 °C - 15 °C hotter than the bulk in the initial 50 hours of burn-in. Power measurements indicate a power drop of 3 - 5% in devices with unpassivated facets in the initial 50 hours, while no such degradation occurs for passivated facets. Thus oxidation is the dominant degradation mechanism and hence cleaning and passivation of the facets is imperative in obtaining stable high power laser diodes.

The second part of this research addressed the passivation of GaSb mesa etched photo diode. Deposition of a few monolayers of sulfur on the wafer surface has been found to passivate the surface dangling bonds. However, the bonds formed by this ultra-thin layer of sulfur are weak and thus with exposure to light and oxygen the effect of passivation is lost. Thus, research and development of suitable capping layers to avoid the disintegration of Ga-S and Sb-S bonds is necessary. Prior capping layer schemes such as, SiN_x and SiO_2 caps have been unsuccessful due to the surface degradation during plasma or sputter deposition of the cap layers. In this research, we have developed a simultaneous passivation and capping scheme using a low temperature ($\sim$85 °C) chemical bath deposition of cadmium sulfide (CdS). The sulfur from cadmium sulfide acts as a passivating species and the CdS film formed by chemical bath deposition as capping layer. Apart from providing the passivating species cadmium sulfide, which is a wider band gap semiconductor can also act as antireflection coating leading to improvement in device performance. There is no strain introduced on the device by the chemical bath deposition method, while other capping techniques like SiN_x and SiO_2 deposition lead to strain and thus device degradation. X-ray Photoelectron Spectroscopic analysis shows the presence of sulfur and $Ga_2/Sb_2\text{-}S_3$ bonds along with cadmium. Reduction in reverse leakage current after passivation is found to be accompanied by significant increase in zero bias resistance area product, from 14.29 $\Omega\text{-cm}^2$ to 100 $\Omega\text{-cm}^2$. Additionally the dependence of zero bias resistance area product on the device dimension reduced considerably.