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The Vertical-Cavity Surface Emitting Laser (VCSEL) And Electrical Access Contribution

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1. Introduction

This proposal chapter aims at highlighting the influence of the electrical access (EA) of different kinds of Vertical-Cavity Surface-Emitting Laser (VCSEL) (Rissons & Mollier, 2009). By presenting an overview of the VCSEL chip electrical equivalent circuit modelling and characterization based on the Scattering parameters, an overview of the VCSEL performance is given to provide a good knowledge of this device behavior in various operation modes and avoid an inadequate utilization of this one (Rissons et al., 2003), (Perchoux et al., 2008), (Bacou, Hayat, Rissons, Iakovlev, Syrbu, Mollier & Kapon, 2009). Due to the emergence of the short distance optical communication, the VCSELs have become, in the last ten years, a key component of the optical interconnections. The current progress in the VCSEL technology makes this laser diode promising for different application fields and competitive with respect to the Edge-Emitting laser (EEL) and the Light Emitting Diode (LED) (providing the laser performance while keeping cost effectiveness of the LED)(Koyama, 2006),(Suematsu & Iga, 2008). Above all the VCSELs have been designed to achieve the need of the optoelectronic circuit planarization. Since its invention in 1977 by Prof. K. Iga (Iga et al., 1988) and its first commercialization at the end of the 90's, the VCSEL structure is in a state of constant progress. Today, a wide wavelength emission range (from the blue-green band up to the infrared) is covered that enables the usage of these components in various application fields, not only in the short distance digital communications (LAN, Avionic network (Ly et al., 2008), ...) but also in consumer applications (laser printers, laser mice, display systems, etc.). All these applications are due to the following features:

- The vertical emission perpendicular to the semiconductor layers makes easier the integration (1D and 2D Array) according to the electrical packaging constraints.
- By combining the small size and the perpendicular emission, this component responds to the criterion of planarization providing a high integration level.
- The low volume of the active layer (AL) due to the quantum wells (QW) involves a sub-milliamps threshold current and a low electrical power consumption.
- The VCSEL presents a low thermal dependence close to the room temperature.
- The serial fabrication reduces the cost and allows on-wafer testing.
- Due to its cylindrical geometry, the light-beam cross section is circular.

All these reasons have led the growth of the VCSEL market in a wide application range especially in the integrated optical sub-assembly of transceiver for short distance optical links.

Despite of the numerous advantages of the VCSEL, the available performance has to be improved to face the Distributed-Feedback (DFB) lasers. This improvement could be achieved thanks to the progress in the VCSEL technology, in particular for the structures of 1.3 and 1.55μm (850nm VCSEL technology being mature since ten years). Another way to enhance the VCSEL performance and avoid an inadequate utilization of this one is to have a perfect knowledge of the component behavior in various operating modes. It can be completed by modeling and by measurements, a particular attention must be paid to the electrical contribution which hugely modifies the frequency response (O'Brien et al., 2007) (Rissons et al., 2003). Moreover, the current advance in VCSEL technology (intrinsic structure and chip submount) requires a constant review of the model and the characterization before the VCSEL utilization (Bacou et al., 2010). Hence we suggest to dedicate a chapter to the VCSEL technology. That aims at giving an overview of the advances, the physical behavior, and the various structures including the electrical access regarding VCSELs.

2. VCSEL Technology

In this section, we introduce the 850nm, 1.3 and 1.55 μm VCSEL technology . Even if the first VCSEL structure emitted at longwavelength(Iga et al., 1988), it is the 850nm GaAs-based VCSEL which emerged at first and came on the market in 2000 (Grabherr et al., 2007). Today the 850nm VCSEL Technoloy is the most competitive and reliable one. All these advantages are due to the maturity of the AlGaAs/GaAs technology and the good performance of the structure (a QW AL between two Distributed Bragg Reflector (DBR)). Recent progress in semiconductor device fabrication gives the possibility to find reliable 1550 and 1310 nm VCSEL (Kapon et al., 2009), (Keun Ho Rhew & Yun, n.d.), (Xu et al., 2009). Various materials and intrinsic structures give the possibility to reach these two ranges of spectrum. A review of the structures is given with emphasis component performance and reliability. In this section, the various VCSEL structures will be also compared with the LED and the DFB to highlight the present and potential usage of VCSELs. Various chip submount are presented. The influence of the electrical access topology is detailed and discussed according to the applications (Bacou, Hayat, Rissons, Mollier, Iakovlev, Sirbu & Kapon, 2009).

3. Optoelectronic model: rate-equations and equivalent circuit model

This section aims at presenting a complete model of VCSEL in order to be able to simulate the VCSEL behavior before its implementation in an optical sub-assembly. Firstly, steady state model and characterization through the light current model is developed. Secondly, we will be interested in the dynamic behavior of the VCSEL. This approach is based on the comparison between the rate equations and an electrical equivalent circuit to get relationships between intrinsic parameters and equivalent circuit elements (Tucker & Pope, 1983),(Bacou et al., 2010). The rate equations are defined according to the VCSEL structure and simplified in compliance with the operating mode. The electrical equivalent circuit approach consists in describing the physical phenomena occurring into the VCSEL structure by resistive, inductive and capacitive elements. The behavioral electrical equivalent circuit is cascaded with the electrical access circuit according to each submount. To write the relationships between VCSEL intrinsic parameters and the circuit elements, the resolution of the rate equation is required.

4. VCSEL Chip Characterisation

This section presents the last step of the study in order to extract the circuit element through the measurement of the scaterring parameters of the VCSEL chip. The measurement of the electrical reflection coefficient (S11) and the optoelectronic transmission coefficient (S21) is achieved by using a Vector Network Analyzer. The experimental setup depends on the VCSEL structure (three different emitting wavelengths: 850nm, 1310nm and 1550nm) and the electrical access. The VCSEL array with a coplanar access could be directly tested by using Ground-Signal-Ground (GSG) RF probes, while the VCSEL array with a microstrip access needs to be mounted on a ceramic submount to be tested on the probe station. The typical TO packaged VCSEL presents a cut-off frequency due to the parasitic effects of the package and could not give directly the VCSEL frequency response. The model is validated by comparing the measurement and the S-parameters simulations by using the ADS^{TM} software. The S-parameters simulations are obtained by implementing the electrical equivalent circuit of the VCSEL and its electrical access in the software. Depending on the electrical access topology, a post-treatment (subtraction procedure (Cartledge & Srinivasan, 1997), modeling by using the transfer matrix formalism (Bacou, Hayat, Rissons, Iakovlev, Syrbu, Mollier & Kapon, 2009)) is required to extract the VCSEL response. All achieved test highlight the mismatching consequence of the TO packaging and electrical line for the optical subassembly of a parallel optical interconnection module. The discussion of the different experimental results provides a critical comparison between the different VCSEL submount.

5. Conclusion

By trying to extract the VCSEL intrinsic parameters from the scattering parameters measurements, the effect of the electrical access on the VCSEL operation is emphasized. The tests of various VCSEL chip provide a sight of the consequence of the mismatched electrical access for the integration in optical interconnection module. This proposal chapter presents a modelling and characterization procedure which is of great interest for the VCSEL manufacturers and VCSEL users.

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