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17 G Directly Modulated Datacom VCSELs

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Abstract: The next generation 850 nm datacom VCSEL to go into production will be the 17 G VCSEL. It is not certain that direct modulation will be suitable given the reliability, supply voltage, and temperature range required. This paper is a first look at VCSELs designed and targeted for production 17 G use. The design is discussed and LIV and small signal frequency response is presented.

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1. Introduction

For short haul datacom such as LANs, 850 nm VCSELs have become the ubiquitous optical solution. 10 G and 8 G devices represent the next large ramp up in volume. Past this the next step is for serial links is 17G. Given the requirements of a 3 volt supply, operation from 0 to 85 C and excellent reliability it is not clear whether directly modulated devices will be sufficient or other methods such as electro-absorption modulators will be required. The implications of these requirements imply a resistance less than 60 ohms for driver headroom, reliability, impedance matching, and minimization of RC time constants. At the same time the aperture diameter needs to drop to ~6-7 microns to achieve adequate 3 db bandwidth. This creates severe design constraints because of the simultaneous small size and small resistance requirements. It is not simply a matter of increasing the doping because free carrier absorption especially in the p-mirror causes an increase in threshold, and decreases the slope efficiency. Because of this there are several aspects of the design which address the interaction of absorption and resistance. In addition to resistance, capacitance must be minimized as the RC time constant is a limiting item. There are additional aspects of the design which allow the minimization of the capacitance.

2. Design and fabrication

The design uses the standard Advanced Optical Components wagon wheel layout shown in figure 1. The oxide connects under the spokes creating a fairly round aperture. The spokes add substantial mechanical stability. A series of proton implants is used to isolate the spokes and close to the oxide aperture and under the top metal to reduce capacitance. Thick silicon dioxide is also used under the reduced size bond pad and the metal runner to reduce capacitance. There are 3 GaAs quantum wells. MBE was used for the entire growth, though MOCVD could have been used.

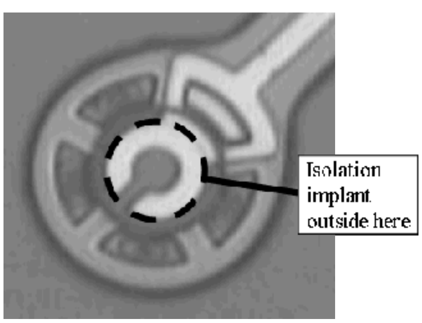

Figure 1. A 7 micron Wagon-wheel VCSEL

The capacitance across the native oxide is minimized in two ways, the isolation implant reduces the radius affecting capacitance and the taper on the oxide increases the thickness of the capacitor at high radii where the area is large. Another parasitic is bond pad capacitance. As stated above this is minimized using thick silicon dioxide, the isolation implant, and a small bond pad. These aspects are important to achieve suitable speed.

A measure of the speed of the actual VCSEL is the relaxation oscillation frequency, ROF, which is given by the equation:

$$ROF = \frac{1}{2\pi\sqrt{\tau_P \bullet \tau_S}} \bullet \left(\frac{I - I_{TH}}{I_{TH}}\right)^{1/2}$$

Where t_p is the photon lifetime and t_s is the spontaneous lifetime. The ROF increases as the ratio of the operating current to the threshold current increases. At high temperatures the threshold current increases and the light output vs. current curve rolls over. To enhance the performance especially at high temperature the threshold current must be minimized while the rollover current is maximized. In addition, there is a tradeoff of the threshold current with the photon lifetime. Higher reflectivity mirrors decrease the threshold current, but increase the photon lifetime which work against each other. In a VCSEL, because of the design constraint provided by free carrier absorption, the optimal is always in the direction of increased photon lifetime and lower threshold current. To achieve a suitably small threshold current small diameter devices with high reflectivity mirrors must be used. Because it is the ratio of the operating current to the threshold current which is important the operating point must be set as high as possible. This is substantially limited at the 85 C high end of operation. To optimize this, the thermal design must be suitable so excess heating is minimized, resistance must be minimized to avoid excess resistive heating, and carrier leakage must be minimized. The structure used here was optimized thermally by extensive use of AlAs in the structure. The resistance was minimized using periodic doping schemes and heavy doping in regions away from the quantum wells. Carrier leakage was minimized with added confining layers.

In addition, the quantum wells themselves could have been improved using either InGaAs or AlInGaAs. Results including such quantum wells such should be available soon.

3. Measurement and Results

Figure 2a shows the LIV characteristic at room temperature. The series resistance is 107 ohms, twice the desired value. Simulation shows this can be brought into the desired range without undue influence on absorption. In spite of this it is one of the lowest resistance devices reported operating in this frequency range.

Microwave measurements, figure 2b, were performed in die form on a special fixture which allowed the use of RF microprobes despite the single top side contact. A detector with a 25 GHz 3 db bandwidth and a 20 GHz network analyzer were used. The oscillation is due to the detector. The 3 db bandwidth is 15.5 GHz at only 4 ma for devices which roll over above 10 ma Most likely the 3db point will be substantially higher for higher current making these likely adequate for 17 G.

While there are no reliability results on these specific devices yet, extrapolation from larger current production devices which achieved substantial reliability improvements imply these should have more than adequate reliability. This of course is dependent on the reduction of the series resistance of the devices.

5. **Conclusion**

Directly modulated 850 nm VCSELs show substantial promise for 17 G applications and are most likely to dominate the market at 17 G when compared to other modulation techniques. The speed has been shown to most likely be adequate, and reliability projections imply reliability will also be suitable. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

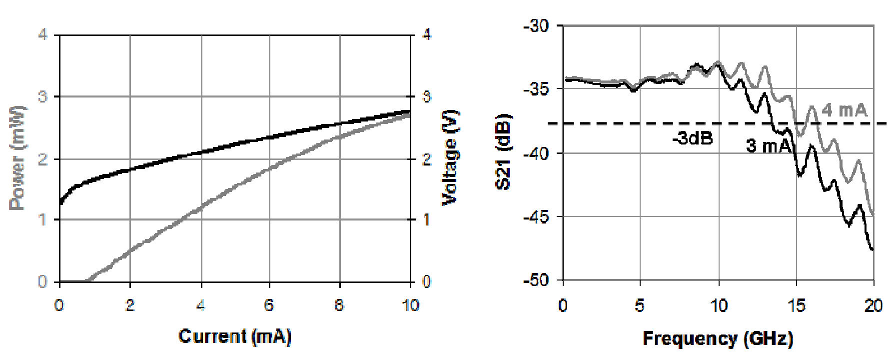

Figure 2a LIV and 2b Frequency response for 3 and 4 ma