High Speed Internet using Opto-Electronic Microprocessors

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***Abstract*—Today, attaining high telecommunication speeds is an important tool for the socio-economic development of a nation. To achieve enormous speeds, optical data connections are more productive, reliable that has a greater data transmission potential than a typical copper-wire network. The optoelectronic microprocessor has the capacity to compute data electronically, but that uses light to move data. The on-chip photonic devices communicates directly with the other chips using light. This technique, using optical interconnect technology could diminish power consumption on the chip and increases the computing speed (performance), unlike the archetypal copper-wire networks that increases power gradually with distance. In these optoelectronic chips, visible light signals are converted into electrical impulses and vice-versa using optical interconnect technology. This technology attains very high speeds in transmission of data using and maximizing bandwidth by encoding different data at different optical wavelengths by using Vertical-cavity surface-emitting lasers (VCSELs). This laser shows modulation bandwidth overshooting 20 GHz, a record for 980 nm VCSELs. Furthermore, 35 Gb/s operation has been attained at only 10 mW power dissipation. This corresponds to a data rate/power-dissipation ratio of 3.5 Gbps/mW. Most significantly, our device structure is reconcilable with existing manufacturing processes and can be certainly manufactured in huge volume making them attractive for optical interconnects.**

Keywords—Optoelectronic chip, high speed, low power consumption, high computing capability,bandwidth,Vertical-cavity surface-emitting laser (VCSEL), optical interconnects;

I. INTRODUCTION

An integrated optical interconnect technology has the potential to exceed the speed of electronics, while it reduce drastically the energy consumption. Significantly greater bandwidth will be allowed by the high-speed, low-loss attributes of optical interconnects. The electrical signals from processors transformed into optical light signals that are dispensed through optical waveguides onto printed circuit boards. Using this technology, a number of high performance processors to control an ever growing data processing workload can be escalated. To transmit the huge quantity of bits in system internal data stream by electrical interconnects is at a premium, losses increase and the high performance electronic constituents recompense these losses. During compensating these losses electronic components generate an appreciable amount of heat, which in turn required energy intensive cooling. Transmitted signals will be distorted due to electro-magnetic interference, when conventional copper lines are place too densely. Optical data communication solves this problem by converting electrical signals into light pulses via optoelectronics, optical data transmission provides the necessary signal quality even at exceedingly high data rates and hence optical interconnects are short reach optical link for high capacity data transfer.

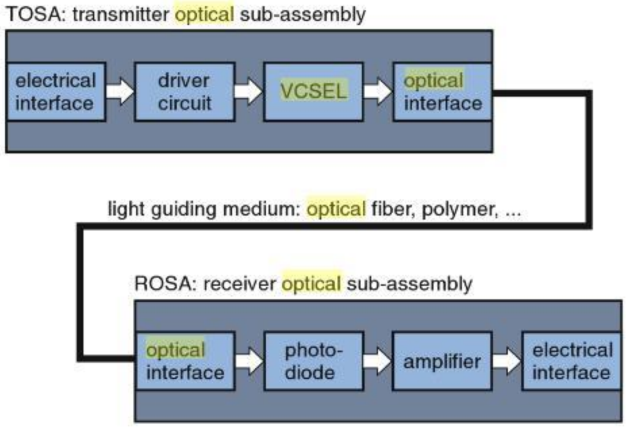

FIG.1

Block diagram of optical interconnect technology consisting of transmitter optical sub-assembly(TOSA), receiver optical subassembly (ROSA) connected by a light guiding medium.

LASER

Vertical Cavity Surface Emitting Laser (VCSEL) is currently the most attractive optical source for the short-distance optical interconnects. A Vertical Cavity Surface-Emitting Laser (VCSEL) is a semiconductor laser diode that emits light perpendicular to the upper surface of the semiconductor wafer of which the laser is constituted. Monolithic arrays of high density VCSELs have been developed by various manufacturers which are competitively priced. VCSELs can be manufactured for several different wavelengths. The devices emitting at around 980 nm represent the most efficient high speed VCSEL technology these devices are top emitting due to large substrate. VCSELs operating at 980 nm are established on GaAs/AlGaAs-based process technology. There are many reasons why VCSELs materializes to be the most optimized optical source in such interconnects. Due to its inherent merit of low power consumption and high speed modulation, it is the only device that can meet 40gbps bit rate. Most of the advantages proffered by the VCSEL technology can be abridged in the following points: 1. Wavelength stability 2. Wavelength uniformity & spectral width, key advantage of VCSEL are low cost, no noise, no frequency interruption, less power consumption, high modulation bandwidth. Because VCSELs emit from the top surface of the chip, they can be put through its paces on-wafer, before they are cleaved into individual devices. This brings down the fabrication cost of the devices. It also allows VCSELs to be built not only in one-dimensional, but also in two-dimensional arrays.

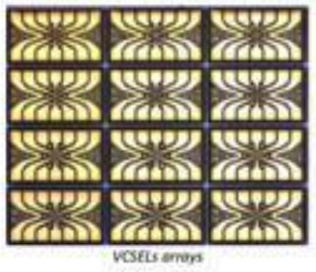

FIG 2

Recently, data rate up to 40 GB/s with a 24 GHz bandwidth has been demonstrated for 1.1 µm wavelength VCSELs. 30 GB/s operation has also been reported for 850 nm wavelength VCSELs .Here we present our work on high-efficiency, high-speed VCSELs emitting at 980 nm wavelengths. The approach show >20 GHz bandwidth and 35 Gb/s operation at only 10 mW power dissipation proportionate to a very high data-rate/power-dissipation ratio of 3.5 Gbps/mW

II. METHODOLOGY

The problem is approached by rerouting of the electrical signals from processor through converter after intercepting the electrical signals. Consequently, optoelectronic integrants are positioned next to processor and connect them using optical fibers for extremely short connections that allow efficient transmission of signals. A chip beside the processor, transform electrical signal from processor to optical signal using the array of lasers. The light pulses initiated, are guided into the optical waveguide by minute mirror. Optical signals received by detectors are transformed back to electrical signals for processor. This system can be scaled by placing various optical-module around the processor. As the performance of microprocessors continues to refine, the data flow to and from the processors becomes an increasingly cardinal bottleneck for the overall system performance. This optical-module enhances the data transmission rate between computers, also boosts the performance of the microprocessors and system.

Electronic data transmission is substituted by optical data transmission in most of the link classes exceeding 10m, profiting from a 1,00,000 times higher carrier frequency, hence avoiding many limitations of electrical interconnects. This approach has most significant advantages and pledges of optics, in this context which includes higher bandwidth x length product, potential cost and decrease in power. The approach focuses on yielding a generic technology platform for a wide range of applications. One main merit of the VCSEL (laser) is, ease of manufacturing and reliability. Therefore they are pertained in many new applications, which can directly aid from these unique attributes. The optical output power dissipation of a VCSEL structure can be given by the equation

$$P_{opt}= N_i * N_d * (I - I_{th}) * hv, \qquad (1)$$

With the internal quantum efficiency i, the optical efficiency d, the current I over the threshold current Ith and the photon energy h. This can be filtered to include more fundamental things like the out-coupling m, internal losses i, transparency current Itr and the gain parameter g0. All the parameters are defined in % per round trip.

$$P_{opt}= N_i * A_m /(A_m + A_i)*(I – I_{tr}*exp((A_m+A_i /g_o))* hv \ldots \quad (2)$$

A comprehensive description of a VCSEL demands information about all these parameters, which are not effortlessly addressable by measuring the LIV curves.

Most of the parameters in equation (2) rely on the internal temperature of this active area, which in itself is indirectly addressable and varies with the current in the device. We presume that the losses i, the internal quantum efficiency I and the gain parameter $_0$ are outcomes of the internal temperature of the device. The threshold current also relies upon the detuning of maximum gain and the cavity resonance.

All measurements and analysis methods are conducted with large area i.e. (100µm in diameter) bottom emitting VCSELs which has emission wavelength of 980nm. The advancement of the VCSEL structures is performed with MBE(**Molecular beam epitaxy)** on n-type GaAs substrates. The AlGaAs n-type DBR grown on the substrate performs as output coupler. The active region composed of threeInGaAs quantum wells. A high-Aluminum containing layer is placed very close to this active region and is oxidized during processing to form an oxide aperture. On top of this active region an AlGaAs p-type DBR with exorbitant reflectivity is grown.

III. SHORT PULSE TECHNIQUES

Laser diode output powers are often cramped by the internal heating of the laser diode. The usage of short pulses allows the measurement at high current without heating up the device, while for cw (continuous wave) measurements the internal temperature varies with the current.

Fig.2 depicts the voltage (a) and output power (b) features of a 100µm large VCSEL device in cw (shown by the solid curves) and with 100ns pulsed (shown by the dotted curves) operation. The internal heating of the laser in cw operation is noticeable in the rounded voltage curve and in the thermal roll-over in the output power.

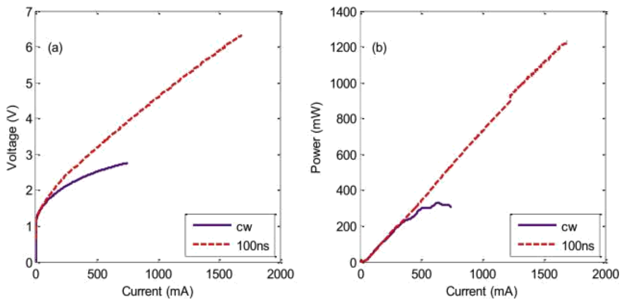

FIG. 3: Voltage (a) and output power (b) of a large diameter VCSEL in CW(continuous wave) operation and short pulses (100ns).

The internal heating of laser diodes can be approximated by instigating a thermal resistance Rth:

$$\Delta T = R_{th} * P_{diss} = R_{th} * (U * I – P_{opt}) \qquad (3)$$

with T (temperature) increase of the active region produced by the dissipated power . The thermal resistance of a small area VCSEL is calculated by measuring the wavelength shift of the laser versus the dissipated power. The laser resonance wavelength varies with the temperature of the resonator due to the amendment in the refractive index and the change of the resonator length. In the large area VCSELs the emission pattern is usually disfigured from a linear refine of the wavelength with the dissipated power and the thermal resistance cannot be extricated from the wavelength measurements. Fig.1embellishes this problem by demonstrating a measurement of the emitted spectrum versus the current for a small diameter as well as large diameter VCSEL's

Therefore this shows that the short pulses overpowers the problem of internal heating during the measurement process and are able to extract the applicable VCSEL limits that are defined for a constant temperature of the active zone.

IV. LIV CURVES FOR CONSTANT INTERNAL TEMPERATURES EXTRACTED FROM CW MEASUREMENTS AT VARIOUS HEAT SINK TEMPERATURES

Once the thermal resistivity of a specific device is known, successive measurements of the continuous wave, current-power behavior over varying heat sink temperature can be used to extricate LIV curves for the constant internal VCSEL temperatures. To know the behavior at constant temperature a whole series of measurements of the light-voltage-current attributes over a wide heat sink temperatures range (-80 to +80°C) is accomplished. The internal temperature of the device contingenting on the dissipated power at every current and heat sink temperature is computed using the formula

$$T_{int} = T_{HS} + R_{TH} * P_{diss}= T_{HS} + R_{TH} * (I * V - P_{opt}) \qquad (4)$$

Each data point composes of its heat sink temperature, internal temperature, current, voltage and output power. There are assorted combinations of heat sink temperature, current, voltage and output power that effects in the same internal temperature. Various data points corresponding to the same internal temperature produces new LIV curves for a constant internal temperature.

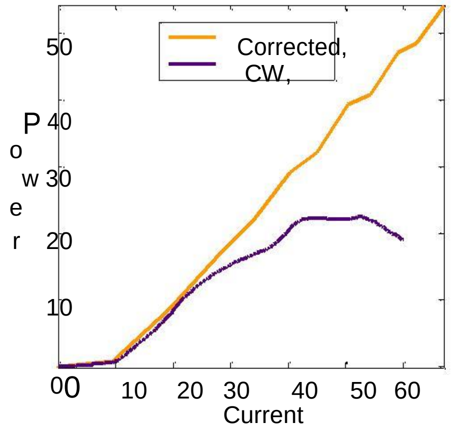

FIG. 4: Comparison of LIV curves of a cw(continuous wave) measurement at constant heat sink temperatures.

Fig. 4 illustrates a direct differentiation of measurements of LI curves at conflicting constant heat sink temperatures (-80 to 60°C) and the extricated curves for constant internal temperatures of 20 to 120°C.

V. INTERNAL LOSSES

The internal losses of VCSELs are determined by altering the mirror out-coupling using the optical feedback.

On adapting the exponential gain model widely used for the broad gain control to derive an equation for the threshold currents:

$$I_{th}= I_{tr}(ext (A_m + A_i) / g_o)$$

with the clarity current, it is the internal losses, mirror out-coupling i and m and the gain constant 0. In VCSELs the mirror out-coupling is explicated by the epitaxial design. Nevertheless, it is still practical to change the mirror out coupling by implementing an external cavity and to impart a part of the emitted light back into the laser. The mirror out-coupling m is then the beneficial mirror out-coupling of the combined cavity steady of the out-coupling mirror of the VCSEL and the external mirror. Light effused from a VCSEL is directed in a straight line by a microscopic lens and reflected back by various dielectric mirrors of defined reflectivity's and transmissions. An unsteady attenuator is placed inside the cavity to further vary the amount of light that is coupled back into the VCSEL. The unsteady attenuator and the detector are moderately tilted to refrain from unconstrained feedback into the VCSEL.

Several oxides restricted bottom emitting 980 nm lasers with various mirror configurations (non-identical number of mirror pairs and mirror doping profiles). Light-current curves of the different VCSELs in the external cavity

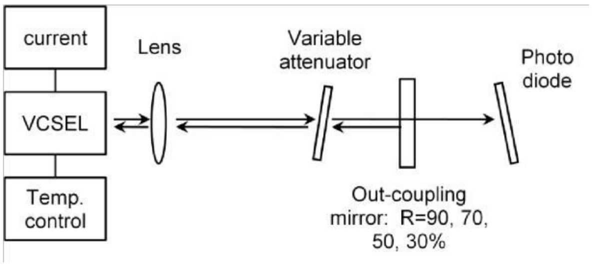

FIG.5: Schematic diagram of the experimental arrangement.

Were taken for various mirror reflectivity's and fluctuating attenuator transmissions, and the threshold current was calculated for every value of the productive reflectivity of the coupled cavity.

The successful reflectivity of the external cavity is ascertained using the transfer matrix method by using the coupled cavity of the VCSEL, the substrate, the changing attenuator and the out-coupling mirror into account. The complex field amplitudes of the incoming and outgoing plane waves for an unpredictable optical system can be connected using the transfer matrix.

For a system composing of various components like the coupled cavity in this analysis the transfer matrices of the alterations between media with several refractive indexes and the generation in each material have to be taken into account. To extricate the absorption in the mirrors we substitute the real and absorbing DBR mirrors with the non-absorbing DBR mirrors. The losses because of the absorption of the mirrors are then a part of the losses of the external cavity and can be known by this analysis proving that the internal losses are very small and are very efficient for data transfer without much loss and without compromising on speed.

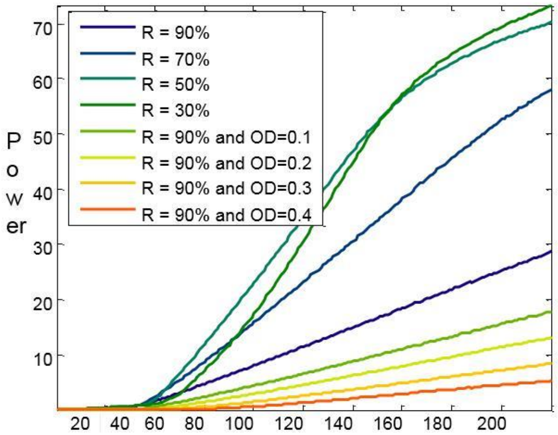

FIG.6: LIV curves with various reflectivities of the external mirror changing from 90 to 30% and with a mirror reflectivity of 90% and different attenuators with optical densities between 0.1 and 0.4.

VI. POWER DISSIPATION AND BANDWIDTH

In general, devices operating between 980 nm and 1300 nm have been probed with great accomplished by various results, most splendid high-speed results are achieved in the wavelength range between 980 to 1100 nm. The main merit is that of the GaAs material. A clear substrate initiates a simple fabrication of the bottom-emitting lasers, rapidly increasing the packaging density. Integration of binary GaAs layers into distributed Bragg reflectors (DBR) importantly increases both thermal and electrical conductivity of the device, paramounting to lower internal temperatures and increasing high temperature stability. They yield higher speed, higher temperature stability, higher packaging density, and reduced power consumption as compared to the conventional wavelength of 850 nm. Indeed the first VCSELs operating at the bit rate of 40 Gbit/s at room temperature and at 25 Gbit/s at higher temperatures are seen at the wavelength of 1100 nm.

Although, the wavelength of 980 nm has many advantages as compared to 1100 nm, among other lower free carrier absorption and more moderate restraints concerning the growth of highly strained QWs, since the judgmental thickness of these layers is greater for the wavelength of 980nm.

Due to these advantages, the fastest VCSELs both at room and higher temperatures operate at 980 nm and bit rates as very high as 44 Gbit/s at 25°C and 38 Gbit/s at 85°C.

CONCLUSION

Optical interconnect is seen as a prospective solution since it can directly address these problems at the system level and meet the performance requirements of current and future generation of data processors and optical interconnects have negligible frequency dependent loss, low cross talk and high band width. By the above results, on using VCSELs, greater bandwidth and less power consumption is achieved , and the need for a higher data bit rate is satisfied, that would initiate faster internet speeds .

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