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A workshop on Low Power Optoelectronics was held at the UCLA Confrence Center at Lake Arrowhead, CA on January 21-23, 1996. This workshop was sponsored by the Department of the Army, Army Research Office, Electronics Division. In this, report, the major topic discussed and general conclusions and recommendations are presented. The reports covers the detailed topics and relevant information as an outcome of the workshop. Also included in this report are the individual abstracts of the invited speakers and participants.

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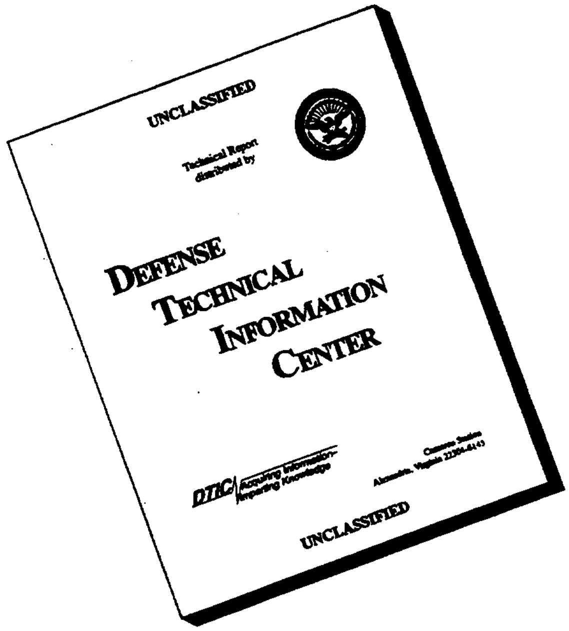

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Report

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Army Research Office

on

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Workshop on Low Power Optoelectronics
(Title)
UCLA Lake Arrowhead Conference Center, Lake Arrowhead
January 21-23, 1996

Submitted

by

Prof. Kang L. Wang, UCLA
Prof. Andrew Steckl, University of Cincinnati
Dr. John Zavada, ARO

Workshop on Low Power Optoelectronics
held at
UCLA Lake Arrowhead Conference Center, Lake Arrowhead, California 92352
on
January 21-23, 1996

Sponsored by the U.S. Army Research Office: Dr. John Zavada
Hosted by Prof. Kang L. Wang, UCLA and Prof. Andrew Steckl, Univ. of Cincinnati

I. INTRODUCTION

A workshop on Low Power/Energy Optoelectronics was held at the UCLA Lake Arrowhead Conference Center during January 21-23, 1996. This workshop was sponsored by the Electronics Division of US Army Research Office (Dr. John Zavada) and addressed topics relating to optoelectronic devices based on the low power, low energy requirements of the Army's plan to develop mobile battlefield systems. The objective of this workshop was to define research issues relating to the development of optoelectronic devices with minimum power/energy consumption. A group of scientists with a wide range of knowledge ranging from materials, devices, and systems were present to assess the state-of-the-art of optoelectronic devices and to identify major research areas leading to improved performance.

The meeting consisted of four sessions focusing on: Light Emitters; Lasers and LED's; Detectors; Signal processing/Storage; and Systems. These sessions focused on the need and prospects of low power optoelectronics, the power/energy requirements of present systems, and, novel methods for signal detection and management. A compiled book of abstracts including the agenda and the list of attendees are attached.

II. MAJOR TOPICS

II.1 Light Emitters: Lasers and LED's

A. Yariv (CALTECH): ***Fundamental Limits and Scaling Laws of Threshold Currents in Quantum Confined Lasers***

A. J. Steckl (University of Cincinnati): ***Focused Ion Beam Fabrication of GaAs-based Optoelectronic Devices***

J. Harris (Stanford University): ***Low Power Quantum Devices***

A. Madukhar (USC): ***Growth-Controlled In-situ Fabricated Quantum Box Structures For Low Power Optoelectronics***

F. Kish (Hewlett-Packard): ***High-Brightness Light-Emitting Diodes***

II.2 Detectors

J. Campbell (Univ. of Texas, Austin): ***Resonant-Cavity Photodetectors and Low-Power Approaches for Optical Receivers***

D. Cooper (Rockwell): ***Low Power CMOS ASICs for IR Focal Plane Arrays***

E. Rosenscher (Thomson-CSF, France): ***Quantum Well Infrared Photodetectors: Performances and New Functions***

J. Zavada (ARO); **W. Chang** (ARL): ***Overview of Focal Plane Array Technology***

R. Jones (Hughes Aircraft Co.): ***Power Management in Infrared Rifle Sights***

II.3 Signal Processing/Storage

R. Trew (ARO): ***U.S. Army Requirements for Low Power Optoelectronics***

T. Itoh (UCLA): ***Low Power/Low Noise Electronics Technologies for Mobile Wireless Communications***

J. Schulman (Hughes Research Lab): ***RTD Low Power High Speed Circuit Applications***

S. Lee (UCSD): ***Reducing the Power Requirements of Electronic Modules and Systems for Information Processing/Storage/Retrieval by Employing Optical Interconnects and Packaging***

U. Efron (Hughes Research Lab/UCLA): ***Concepts for Opto-Electronic Co-Processors***

III. GENERAL CONCLUSIONS/RECOMMENDATIONS

To date, the reduction of power optoelectronic devices has not received adequate attention either in research efforts or system design. The Army goals for optoelectronic components are light weight, low power, and low cost in manufacturing.

From the presentations and discussions in these four areas, it is clear that new innovative approaches are needed in the areas of detectors/emitters, signal processing and systems for the wireless platform.

III.1 General

Innovative research in low power/low energy optoelectronics must consider the system needs of the Army's fully mobile digital battlefield platforms. In order to satisfy the requirements, the research needs to focus in the low power operation of optical/optoelectronics devices, signal processing and system optimization. The operation of optoelectronic systems may also involve other related elements. Transmission and reception of audio, video signals and data can be made via optical and microwave and millimeter waves or the mixed mode. The mixed mode operation and integration will require the innovations in materials/devices and signal processing algorithms and system concepts/implementation.

III.2 Specific

A. Material and Device Technology

- Innovative research in material and device technology is needed for new optical emitters/detectors for low noise optoelectronics and microwave and millimeter waves and mixed mode operation.

- New materials using layered structures and quantum effects (near room temperature) for achieving low power devices in nonlinear optics and infrared detection.

- New materials/structures and devices for high operation temperature for infrared detector arrays.

- New means for fabrication of nanostructure arrays for detectors and emitter arrays using new self assembly techniques.

- Investigation of linear and nonlinear optical properties of self assembled stacked structures.

- Using MEMS for micro-optic components to achieve innovative mixed technology.

- Novel means of monolithic integration of optoelectronic/microwave devices.

B. Signal Processing

- For signal processing application in the digital battlefield scenario request, high volume and real time information processing is needed, particularly for video signals. There is a need for new innovative approaches for signal processing such as imbedding signal processing/storage in detector arrays in order to achieve low power/low energy multi-functionality operation which will be crucial to reduce the total devices and hence, to achieve high degree of integration.

- Innovative all weather low voltage and low noise optical transmitter/receiver (arrays).

- Innovative means of imbedded signal processing functions in the imaging and receiver detector arrays for high speed and low power operation.

- New WDM and CDMA signal processing algorithms for high efficiency operation.

- Low noise signal processing units for low voltage (and thus low power)

- Innovative optical parallel processing using arrays.

C. Systems

- Low power system integration is crucial for achieving the overall objective of mobile digital battlefield.

- Low power/Low voltage optical emitter/transmitters and receivers for high speed signal links.

- Integration of multi-functionality in signal processing/transmitter/receiver units with imaging arrays.

- Prototyping: MCM prototyping for integration of focal plane arrays (FPA) and signal processing units and transmitters and receivers.

- Low power human interface system concepts.

Workshop on Low Power Optoelectronics
UCLA Lake Arrowhead Conference Center, Lake Arrowhead, California 92352
January 21-23, 1996
Sponsored by the U.S. Army Research Office: Dr. John Zavada
Hosted by Prof. Kang L. Wang, UCLA and Prof. Andrew Steckl, Univ. of Cincinnati

Program

Program will cover the following subject areas:

January 21, 1995 (Sunday)

3:30-6:00 p.m. **Arrival/Conference Registration/Check-In**
6:00-6:30 p.m. **Social Hour**
6:30 p.m. **Dinner Served**

EVENING SESSION-OVERVIEW

A. Needs and Prospects for Low Power/Energy Optoelectronics

Army Goals

8:00-8:20 p.m. **Introductory/Welcome Remarks,** Dr. John Zavada, ARO and Dr. Kang L. Wang, UCLA

8:20-8:40 p.m. **U.S. Army Requirements for Low Power Optoelectronics,** Dr. Robert Trew, ARO

Army MURI

8:40-9:00 p.m. **UCLA-MURI Program: Low Power/Low Noise Electronics Technologies for Mobile Wireless Communications,** Prof. Tatsuo Itoh, UCLA

Wireless Communications

9:00-9:40 p.m. **Microwave Optical Interactions,** Prof. Tatsuo Itoh, UCLA

Free Forum Leader: Dr. John Zavada

****

January 22, 1996 (Monday)

8:00-9:00 a.m. **-BREAKFAST -**

B. Optoelectronics Devices and Power/Energy Requirements

Lasers/Optical Interconnect

9:00- 9:40 a.m. **Fundamental Limits and "Scaling Laws of Threshold Currents in Quantum Confined Lasers",** Dr. Amnon Yariv, CALTECH
9:40-10:20 a.m. **Resonant-Cavity Photodetectors and Low-Power Approaches for Optical Receivers** Prof. Joe C. Campbell, Univ. Texas, Austin
10:20-11:00 a.m. **Growth-Controlled *In-situ* Fabricated Quantum Box Structures For Low Power Optoelectronics,** Prof. Anupam Madhukar, USC

11:00-11:15 a.m. **-BREAK-**

11:15-11:55 a.m. **Focused Ion Beam Fabrication of GaAs-based Optoelectronic Devices** Dr. Andrew J. Steckl, Univ. of Cincinnati

Power Management in Optoelectronics

11:55-12:30 p.m. **Power Management in Infrared Rifle Sights,** Dr. Russ Jones, Hughes

12:30-1:30 p.m. **-LUNCH-**

<u>**Light Emitters/High Brightness on LED's**</u>

1:30-2:10 p.m. **High-Brightness Light-Emitting Diodes,** Dr. Fred Kish, Hewlett- Packard

<u>**Photodetector/IR Imaging**</u>

2:10-2:50 p.m. **Quantum Well Infrared Photodetectors: Performances and New Functions**
Dr. Emmanuel Rosencher, Thomson- CSF

2:50-3:30 p.m. **Low Power CMOS ASICs for IR Focal Plane Arrays,** Dr. Lester Kozlowski, Rockwell
to be presented by Dr. Donald Cooper, Rockwell

3:30 p.m. **FREE TIME**
6:00 p.m. **Social Hour**
6:30 p.m. **Dinner Served**

<u>**Photodetector/IR Imaging**</u>

8:00-8:40 p.m. **Overview of Focal Plane Plane Array Technology,** Dr. John Malamas, USARL
to be presented by Dr. John Zavada, ARO

<u>**Quantum Devices**</u>

8:40-9:20 p.m. **Low Power Quantum Devices,** Prof. James Harris, Stanford University
9:20-10:00 p.m. **RTD Low Power High Speed Circuit Applications,** Dr. Joel Schulman, Hughes

Free Forum Leader: Dr. Robert Trew
****

January 23, 1996 (Tuesday)

8:00-9:00 a.m. **-BREAKFAST**

C. Systems and Information Management

<u>**Information Processing/Storage/Retrieval**</u>

9:00-9:40 a.m. **Reducing the Power Requirements of Electronic Modules and Systems for Information Processing/Storage/Retrieval by Employing Optical Interconnects and Packaging,** Prof. Sing H. Lee, UCSD

<u>**Systems/Networks**</u>

9:40-10:20 a.m. **Concepts for Opto-Electronic Co-Processors**
Dr. Uzi Efron, Hughes/UCLA

10:20-11:00 a.m. **High Density Wavelength Division Multiplex and Components**
Dr. Siamak Forouhar, JPL

11:00-11:15 a.m. **-BREAK-**

11:15-12:00 a.m. **WRAP-UP SESSION**

Free Forum Leader: Dr. John Zavada, Prof. Kang L. Wang, Prof. Andrew Steckl

12:00-1:30 p.m. **-LUNCH-**

1:30 p.m. **Check-out/Departure**

UCLA MURI Program
on
Low-Power/Low Noise Electronics Technologies for Mobile Wireless Communications

(with UCSD and Rockwell)

T. Itoh
UCLA Electrical Engineering Department

ABSTRACT

Future Army requires mobile multimedia wireless communications. As these systems becomes more sophisticated, the electronic circuits and components become more complex. The challenge is to make them much more efficient so that prime power requirement is reduced by an order of magnitude or more, since the battery technology does not seem to have a breakthrough in the near future. Unlike the conventional wireless communication, the Army requires many unique features. For instance, the conventional base station concept should be modified and the microwave and millimeter wave frequencies must be used. At such higher frequencies, the reduction of the power consumption at the baseband alone is not sufficient, but much more efficient front-end structures than the currently available ones need to be explored. UCLA/UCSD team has been selected together with University of Michigan to explore this challenging research area under the 1995 MURI program from ARO. The program in interactive among participants and address many new concepts for efficient microwave front end technology. The program consists of 6 interactive units. (1) Development of HBTs with wide bandgap collectors and their use in ultra-high efficiency power amplifiers (UCSD/UCLA/Rockwell), (2) Development of complementary HFET based on (Ga, Al)InP/InGaAs epi structures (UCSD), (3) Innovative devices with squeezed noise (UCLA), (4) Microwave and RF front-end and antennas (UCLA), (5) MEMS for RF circuits and antennas, and (6) Applications to battlefield communications (UCSD). There are 5 investigators from UCLA, 4 from UCSD and 2 from Rockwell participating in the 5 year $4 million program. Several projects for the first year have been identified and initiated.

Workshop on Low Power Optoelectronics
January 21-23, 1996, Lake Arrowhead

Microwave Optical Interactions

T. Itoh
UCLA Electrical Engineering Department

ABSTRACT

Appropriate recognition and implementation of microwave-optical interaction can provide an increased functionality for microwave circuits, more efficient use of circuit real estate, and an opportunity to develop new configurations or substantial improvement in existing requirement. This paper reviews some of the projects using microwave-optical interactions at UCLA. The topics include an optical control of active antenna (quasi-optical oscillator), beam steering and beam switching of phased arrays with injection locking signal transported by a gain-switched DFB laser, and a novel high power-high frequency photodetector based on the principle of microwave traveling wave amplifier.

In the first topic, the additional interconnect problem for the MMIC already crowded by complex circuit topology is alleviated by optical off-the-chip access of the control signal. The optical control signal effectively changes the three-terminal microwave devices to four terminal devices. Therefore, for this scheme, the optical signal is used simply as bias for active devices. Examples of this technique include the control of the oscillation condition of the quasi-optical microwave oscillator and the optical switching of the antenna beams from a coupled active antennas.

In the second topic, the antenna remoting is accomplished by optical fiber. However, unlike many other approaches, the microwave functions are preserved as much as possible so that the overhead to the optical regime is kept minimum. The particular structure is a phased array without conventional phase shifters. The microwave signal generation and processing are distributed at the antenna front ends. The phase shift needed for beam steering or beam switching is accomplished by the injection locking signal which is transported from a remote site via an optical link. The optical link can either be passive or active. In the former, the microwave injection signal simply modulate the optical output from a laser diode and is extracted at the antenna site by a photo detector. In the active system, the gain-switched DFB laser generate several harmonics of the modulating signal. Hence, the higher harmonics can be extracted at the antenna site for beam control. This technique is particularly suited for antennas at millimeter wave frequencies where the cost of coherent source becomes increasingly expensive.

In the third example, the concept of microwave traveling amplifier is used for broadband high power photodetector system. Active photo diodes are periodically distributed along the optical waveguide. Each photo diode picks up a small fraction of input light so that it does not saturate. The unused light is detected by the subsequent photodiode. The microwave outputs are collected by a microwave transmission line in a velocity-matched manner. Since the individual diodes do not need to handle a large optical power, they can be optimized in terms of bandwidth. Some simulated results and recent experimental progress will be presented.

Fundamental Limits and "Scaling Laws of Threshold Currents in Quantum Confined Semiconductor Lasers"

A. Yariv

ABSTRACT

We will review the concept of transparency and the transparency inversion in semiconductor media. We will relate the transparency condition to the problem of achieving ultra low threshold currents in quantum confined lasers. We will show that although sub microamperes threshold currents are theoretically possible, the need to override receiver noise in real word links greatly diminishes the returns below a certain threshold level.

Resonant-Cavity Photodetectors and Low-Power Approaches for Optical Receivers

J. C. Campbell
Microelectronics Research Center
University of Texas, Austin, Texas 78712 (512-471-9669)

Prior to the demonstration of semiconductor lasers with threshold currents less than 100 μA, power dissipation in optical receivers appeared to be less crucial than that in the transmitter. However, recently the focus has begun to shift to the receiver. This is due in large part to the fact that the output powers of the ultra-low-threshold lasers is relatively low but at the receiver there is still a need to have output signal levels near 1V. The resulting need to increase the gain in the receiver has, in a sense, shifted the "power problem" from the transmitter to the receiver. There are a number of approaches that may prove effective in reducing the power dissipation in the receivers and this talk will attempt to outline some of them.

One of the difficulties lies in the nature of the receiver circuit itself; namely, that it is an analog amplifier and the transistors must be biased continuously. The most straightforward approach is to simply reduce the voltage and current in the present preamplifier circuit designs. This will lead to higher capacitances and lower transconductances. To compensate it will be necessary to focus on minimizing all critical capacitances. This may be accomplished with creative applications of dielectrics and semi-insulating materials. Scaling the transistor dimensions to lower values would recover the loss of transconductance and lower the capacitances with almost no down side.

Recently, a lot of research has focused on developing new circuit designs to reduce the power in low-speed (< 500 MHz) analog circuits. Some of the approaches are current mirrors, dynamic bias, bandgap references in low-voltage regulators, folded cascode configurations, and complementary push-pull circuits. It may prove productive to modify conventional receiver circuits to include some of these design techniques.

A third approach would be to incorporate active, low-noise gain prior to the electrical preamplifier. Two candidates are avalanche photodiodes (APDs) and optical amplifiers. The APD has the advantage that it is a single semiconductor component that can easily be packaged (or perhaps integrated) with the receiver electronics. In addition, it provides adjustable gain control if needed. The APD could be used in different ways. One approach might be to use the APD in a very low gain mode ($M \sim 3$) to reduce the needed gain (and power) in the preamplifier. In this mode, the bias voltage and temperature control usually required for APDs could be relaxed somewhat. Very high gain APDs could be used with present circuits if the multiplication noise can be significantly reduced by using low-noise structures such as the multiple-quantum-well APDs. Optical amplifiers would be most attractive if integrated, waveguide structures that are amenable to arrays could be developed.

If APDs are to be deployed for low-power applications, it may be an advantage to reduce the bias voltage. We have demonstrated that the resonant-cavity structure can provide avalanche gains > 100 at biases in the range 10 to 15V, a factor of 5 to 10 lower than conventional APDs. The APD that has been widely deployed for long-wavelength, high-bit-rate optical transmission systems, the SAM-APD, utilizes separate absorption and multiplication structures. We have successfully incorporated the SAM APD into a resonant-cavity structure. It consisted of a 500 Å $In_{0.1}Ga_{0.9}As$ absorption layer, an $Al_{0.4}Ga_{0.6}As$ multiplication region, and AlAs/GaAs Bragg mirrors. These SAM-APDs exhibited excellent characteristics: high external quantum efficiency (η=74%), high gain ($M > 30$), low breakdown voltage ($V_b < 14$ V), and low dark current ($i_d < 10$ nA @ 90% of V_b). The excess noise factor of the resonant-cavity SAM-APD corresponded to an ionization coefficient ratio, k, of less than 0.3. This is comparable to that of multiple-quantum-well APDs.

ARO Workshop on Low Power Optoelectronics (Lake Arrowhead, January 21-23, 1996).

Growth-Controlled *In-situ* Fabricated Quantum Box Structures for Low Power Optoelectronics

Anupam Madhukar
Photonic Materials and Devices Laboratory
Departments of Materials Science and Physics
University of Southern California
Los Angeles, CA 90089-0241

Low power optoelectronic devices are essential to the development of a variety of high throughput information processing and computing systems requiring high density arrays. Nanostructures (quantum wires and boxes) exhibiting quantum confinement effects have been theoretically anticipated to provide ultra low power operation of a variety of devices based upon quantum effects. Experimental realization of such nanostructures, however, poses many challenges pertaining to the growth, processing and, in some cases, regrowth steps, apart from the challenges of design and communication with the external environment. In this talk I shall focus on *in-situ*, purely growth-controlled approaches to the realization of high quality semiconductor nanostructures via (a) growth on nonplanar patterned substrates and (b) exploitation of strain induced 3D island formation in highly lattice mismatched epitaxy. Results for the InAs / GaAs (001) based quantum box structures suitable for operation in the 0·9μm to 1·3μm regime will be presented with emphasis on growth / processing, structural properties, and spatially-resolved optical properties. In particular, fabrication of novel vertically self-organized 3D island quantum box based laser structures will be discussed along with some preliminary results of the lasing characteristics.

FIB Fabrication of GaAs-based Optoelectronic Devices

A. J. Steckl
University of Cincinnati
Cincinnati, OH 45221-0030

Great progress has been made in recent years in the development of optoelectronic integrated circuits (OEIC). One source limiting the expansion of OEIC capability has been the complexity required for fabrication using conventional technology (in particular lithography and etching), which has to satisfy various requirements for different components fabricated on the same substrate. In this paper we review an alternative microfabrication approach which utilizes FIB implantation as a versatile maskless and resistless process. FIB implantation has been used to fabricate several GaAs-based optical devices, including channel waveguides, wires, gratings, mirrors, lasers. The FIB techniques utilize either direct micro-milling, implantation doping or ion-induced compositional mixing of multi-layer structures. In addition to the advantages of a high resolution maskless/resistless process, the FIB approach benefits from being able to readily adjust the implantation conditions (such as dose, energy, sometimes even species) in order to customize the process for each type of component during a single step.

The FIB fabrication techniques and selected FIB-fabricated optoelectronic devices will be reviewed. One of the main items which will be covered is the FIB-induced mixing of superlattice structures. We will discuss the mechanisms for this process based on a comprehensive study of Si+ FIB implantation into a short period Al0.3Ga0.7As/GaAs superlattice structure. The effect of ion energy, dose, and RTA conditions on the FIB-induced mixing will be summarized. In the implanted region, the inter-diffusion causing compositional mixing was found to be significantly enhanced by the Si FIB implantation. An ion dose of 1=A51014/cm2 results in a two-order of magnitude increase in the inter-diffusion coefficient. Further mixing enhancement (pinch-off mixing) was observed at certain depth. The depth-dependent mixing is attributed to vacancy injection. A model based on the experimental results will be introduced.

Among the simpler device structures to be reviewed are FIB-fabricated mirrors, channel waveguides and wire arrays. For example, single mode channel waveguides with widths of 4-8 =B5m have been fabricated with relatively low loss using FIB mixing. Anisotropic exciton diffusion, indicating lateral exciton confinement, was observed by localized photoluminescence in wire structures fabricated by FIB mixing.

Maybe most significant, fabrication of distributed Bragg reflection (DBR) lasers using either FIB doping or mixing technology will be presented. For example, third order quantum well DBR lasers were fabricated by a single-step, maskless FIB mixing of a GaAs/AlGaAs superlattice structure. Each DBR reflector consisted of an array of implanted lines with a period of 350 nm. Lasing operation was achieved at a wavelength of ~ 827 nm, with a linewidth of 1.5 =C5.

The paper will conclude with a discussion of methods and issues in integrating the fabrication of multiple optoelectronic components using FIB technology.

Power Management in Infrared Rifle Sights

Russ Jones
Hughes Aircraft Company
Phone: (310) 616-4951

The successful fielding of a low power IR sight requires a systems approach to power management. This briefing takes a look at power management in the Thermal Weapon Sight, a rifle sight for the Army with stringent power requirements. Opportunities for further power reductions in both thermoelectrically cooled and uncooled sensors are also discussed.

High-Brightness Light-Emitting Diodes

F.A. Kish
Hewlett-Packard, Optoelectronics Division, 370 W. Trimble Rd., San Jose, CA 95131

Recently, significant improvements in light-emitting diode (LED) performance have been achieved with the development of AlGaInP (red-orange-yellow-green) and AlGaInN (green-blue) emitters. The luminous performance of these devices is such that they are now competitive with that of filtered and unfiltered incandescent sources. As a result, these devices are being targeted for a variety of new market applications which include large-area displays, power signaling, and low-power applications. This talk will review AlGaInP LED technology recently developed at Hewlett-Packard as well as recent advance in Nitride-based LEDs.

Quantum Well Infrared Photodetectors: Performances and New Functions

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Quantum well infrared photodetectors are a new family of mid-infrared (3 - 12 µm) detectors based on the optical intersubband transitions in low dimensionality semiconductor heterostructures. In this communication, we will adress the following points:

- physics, device modeling and optimisation of QWIPs
- actual and extrapolated performances of QWIPs arrays in bands II and III
- new functions (multispectrality, tunability, band switching, optical reading...)

Low Power CMOS ASICs for IR Focal Plane Arrays

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By exploiting submicron CMOS processes and high quality HgCdTe detectors grown by either liquid phase or molecular beam epitaxy, we are aggressively developing high performance infrared focal plane arrays for many applications including astronomy, spectroscopy, surveillance and conventional imaging. Each hybrid focal plane array typically consists of a photovoltaic HgCdTe detector array, which is fabricated on Al_2O_3 or CdZnTe substrates and has photoresponse cutoff wavelength optimized for each application, hybridized to a CMOS silicon readout via indium column interconnects. In this paper we focus on the characteristics of the readouts/ASICs including ultra-low power, low noise and low self-emission (MOSFET "glow" stemming from hot carrier effects). Amplifier power dissipation less than 1 pW, for example, has been achieved in pixel pitch significantly less than 40 µm by exploiting both the analog-compatible CMOS process, submicron lithography and pipelined readout architecture.

We report recent results on our 1024x1024 FPA for astronomy and introduce a second 1024x1024 having capability for operation at TV-type frame rates. The latter device also has low read noise but at much higher bandwidth by virtue of its capacitive transimpedance amplifier (CTIA) input and pipelined readout architecture. Though each pixel has a dedicated amplifier with open-loop gain of about 500, the total power dissipation for the readout is only 38 mW including the two Class AB output amplifiers and the quiescent power dissipation for each pixel is 20 only nW. We also compare the read noise achieved with the source follower per detector input used in the astronomy FPA to the CTIA scheme. Both devices have been shown capable of consistently achieving background-limited sensitivity at very low infrared backgrounds ($\leq 10^9$ photons/cm^2-sec) by virtue of their low read noise, low dark current including negligible MOSFET self-emission, and high quantum efficiency. 1024x1024 HgCdTe FPA pixel operability has recently been increased to 99.94% with mean peak D* of 10^{14} cm-Hz$^{1/2}$/W.

Overview of Focal Plane Array Technology

John Malamas
U.S. Army Research Laboratory

A review of the types of imaging sensors currently in use will be presented. The present generation of detector materials and devices is summarized, and some of the future technologies are identifed and discussed. Examples of fielded army systems will be described.

Low Power Quantum Devices

James S. Harris
Stanford University

Low power has not been the primary focus for optoelectronics. However, if wireless and mobile communications, computing and display with very large data transfer rates are to become a reality, then very low power will become a primary driving force. One of the fundamental views we have adopted in this regard is that switching and computing architectures will have to be photonic and "conservative," i.e. based upon pure phase, polarization, directional or delay modulation so that photons are not lost in the communications process rather than amplitude modulation or lossy photon/electron conversion and electronic switching. Toward these goals, we have worked on a variety of quantum well and quantum dot device structures for modulation, beam switching and wavelength tuning that will be applicable to low power architectures.

At the materials level, we have developed both coupled quantum well structures and self assembled quantum dot structures which provide greater non-linearities and lower operating voltages. MBE growth of both the coupled quantum well structures and self assembled, vertically coupled InAs quantum dots will be reviewed with respect to low power optoelectronic devices.

At the device level, we have developed a pure phase modulator and a new reversible X-modulator, an optical switch which is logic conserving. The X-modulator is switched electronically, but operates on photons incident from both sides and either reflects both beams or transmits both. We have also used the phase modulator to produce a programmable grating capable of high speed photonic switching and laser beam steering. both of these devices will be described.

Finally, we have combined micro-machining with a vertical cavity laser to produce the first monolithic, broadly tunable semiconductor laser. This laser is continuously tunable over 18 nm. The elements of micro-machined tunable cavities and their application to lasers and highly selective tunable detectors for wavelength division multiplexing and frequency agile free space communications will be described.

RTD Low Power High Speed Circuit Applications

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Double barrier resonant tunneling diodes are quantum effect devices which produce negative differential resistance current-voltage characteristics at room temperature. The thinness of the epitaxially grown active layers implies high speed operation in the high gigahertz range. The negative resistance region provides bi- and multi-stable operating points which provide opportunities for reducing circuit complexity by reducing the transistor count and thus power requirements. Compatability with III-V growth and processing allows integration with conventional GaAs and InP-based HBT and HEMT fabrication techniques. A level of maturity in RTD technology has been achieved such that a variety of circuits have been proposed and prototypes demonstrated, including digital circuits with a complete logic family operating at 12 GHz. In this talk present understanding of RTD physics, device concepts, and sample circuit implementations will be discussed.

Reducing the Power Requirements of Electronic Modules and Systems for Information Processing / Storage / Retrieval by Employing Optical Interconnects and Packaging

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ABSTRACT:

In earlier presentations in this workshop the issues of reducing power / energy requirements of optoelectronic devices have been addressed. This presentation concerns with the power requirements of modules and systems when many electronic and optoelectronic devices are connected together. Specially it concerns how to reduce the power requirements of interconnection, not the power requirements for processing.

In references 1 and 2 it is shown that optical interconnects require less power / energy than electrical interconnects for connecting electronic devices together, when the interconnect distances exceed several millimeters and the circuit bandwidth above 100 Mb/s. Recently, it is also widely accepted (Ref. 3) that optical interconnects require less power / energy than electrical interconnects for connecting many electronic modules / systems together (using fiber ribbons), when the interconnect distances exceed several meters and the module / system bandwidth above 100 Mb/s. Thus, within the range of several millimeters to several meters of interconnection distances, research should also be carried out to ensure that optical interconnects will be advantages over electrical interconnects in power / energy.

At the backplane level, where many printed circuit boards (PCBs) are to be connected together with interconnection distances approximately a meter, electrical interconnects is beginning to experience difficulties currently when the number of boards to be connected exceeds 15 and the channel bandwidth approaches 300 Mb/s. According to the SIA roadmap, it is projected that electrical interconnects can accommodate 500 Mb/s per channel speed between boards only after year 2010, while 50 Gb/s aggregate throughput for a (multi-channel) wide data bus will be needed for cost-sensitive applications by 1998. (For high performance / cost applications the aggregate throughput needs can be as high as 700 Gb/s.) The preliminary investigations we perform recently indicate that power saving of at least 25% can be attained using optical interconnects, while the design difficulties of electrical interconnects (e.g. transmission line impedance matching and termination) experienced by electrical interconnects can be overcome and more PCBs can be connected together. These advantages of optical interconnects need to be verified by experimental demonstrations with prototype constructions.

At the board level, where many electronic chips are to be connected together with interconnection distances in the range of one to several tens of centimeter, our preliminary studies show that power saving of 50% can be achieved when the electronic processing / storage elements are properly placed in different wafers / MCMs (multi-chip modules) and the interconnections are properly partitioned between electrical and optical on the PCB for a given system architecture (Ref. 4). Research issues here include placement and partitioning algorithm development and experimental demonstration with prototype construction.

To support optical interconnects at the backplane and board levels, component assembly and module packaging technologies will need to be developed. Critically important to the assembly of optoelectronic components and the packaging of optoelectronic modules is optical alignment, which could have serious effects on the power requirements of the modules / systems. Because of cost considerations the preferred techniques will be passive, self-aligned, applicable to make many connections simultaneously in batches and as compatible to existing electronic packaging techniques as possible.

When the necessary algorithm research in partitioning optoelectronic systems for optimized interconnect usages and the technology development for optical interconnects and packaging are accomplished, the resulting system interconnection power will be reduced with respect to the system with only electrical interconnects.

References:

1. M. R. Feldman, S.C. Esener, C.C. Guest, and S. H. Lee, "Comparison between optical and electrical interconnects based on power and speed considerations," Applied Optics 27 (9): 1742-1751, May 1, 1988.

2. D. A. B. Miller, "Optics for low-energy communication inside digital processors: quantum detectors, sources, and modulators as efficient impedance converters," Optics Letters 14, (2): 146-148, January 15, 1989.

3. ARPA has recently sponsored several R/D programs to demonstrate optical interconnects between electronic modules / systems using fiber ribbons of several meters lengths: OETC (AT&T, Honeywell, etc.), POINT (GE, Honeywell, etc.), POLO (HP, AMP, etc.).

4. J. Fan, B. Catanzaro, V.H. Ozguz, C.K. Cheng, S.H. Lee, "Design considerations and algorithms for partitioning optoelectronic multi-chip modules". Proc. ACM & IEEE First International Workshop on Massively Parallel Processing Using Optical Interconnects, pp. 59-69, April 1994, Cancun, Mexico.

Concepts for Opto-Electronic Co-Processors

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The two important trends in current computing system design are high computational throughput and low power consumption.
One way of accomplishing simultaneously these goals is by the use of Opto-Electronic-based Co-Processors. Four examples of such systems/components will be described:
(1) Optical correlator
(2) Smart Imager/SLM
(3) Optical Memory
(4) Optical Interconnects
The Optical Correlators can offer a significantly reduced power--consumption (relative to an all-electronic processor), through the optical multiplexing advantage.
The Smart Imager/SLM device allows efficient use of the CCD circuitry to perform spatial light modulation and spatial imaging,making a more efficient use of the biasing power.
The Optical Memory allows an efficient,zero storage- power consumption, combined with ultra-high density storage of data/imagery.
Finally, Optical Interconnects can allow efficient,global interconnections between Wafer-Scale or, DSP-based Preocessing Elements, again allowing potential reduction in power consumption.
These four concepts of Optoelectronic processors and components will be discussed.