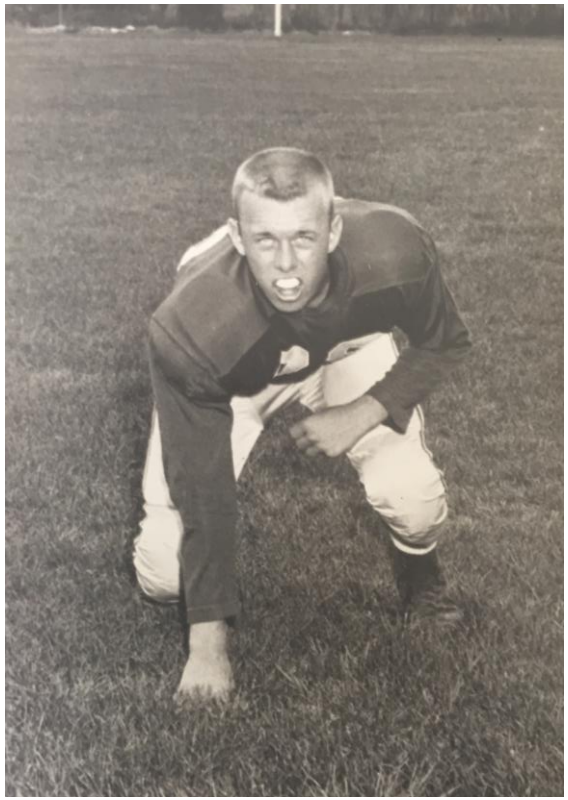
A HISTORY OF PICs AND VCSELs:
Tribute to the Career of Larry Coldren

Milan Mashanovitch (UCSB Ph.D. 2004)
Freedom Photonics LLC
16 March 2018

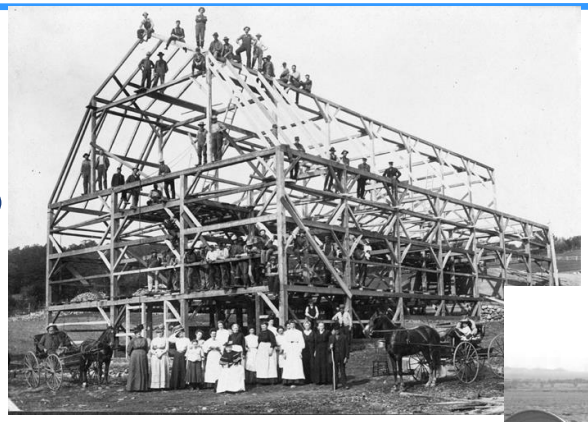
Early life – Mifflintown, Pennsylvania

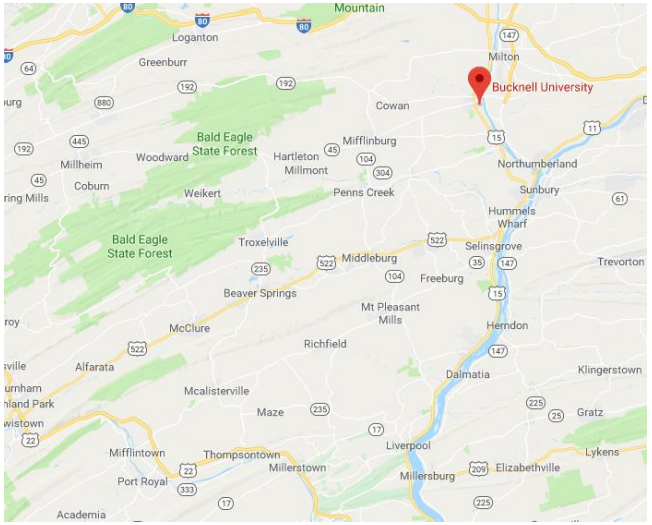
- Larry was born on first day of baby boom, January 1, 1946 in Mifflintown, central Pennsylvania…
- He grew up on a large farm…



Early training and education

- According to Larry, living at a farm, there was always equipment to fix, and structures to build…. So he became proficient with mechanical and civil engineering
  - Enlisting brother for help in execution
- So, when choosing a major at Bucknell University, he decided on electrical engineering
  - "I did not know anything about it"
- Double major in Physics and Electrical Engineering
- Summer internships at IBM





Employment with Bell Labs and Stanford M.S. and Ph.D.

- Larry graduated with honors from Bucknell in 1968
- Fellowship offer from MIT vs employment offer from Bell Laboratories
  - Military systems division, working on development of early version of missile defense and anti-EMP
- Larry chose Bell Laboratories, in part due to the moment in history and Vietnam war
  - Masters needed to work at Bell
  - 1 year program with Stanford
- At the end of master program, offered to continue to Ph.D. on a Bell Lab stipend
  - Recession and budget cuts made it favorable to defer hiring
- Extra 3 years of Ph.D. work

OR

Bell Laboratories

=

Early work at Bell Labs, and IEEE Fellow Status

- After his PhD, at Bell Labs, Larry joined Bell Labs research
- Larry worked on surface acoustic wave devices
  - Used for signal processing, storage of high-data rate signals
- Result of this work – timing recovery filter, deployed in TAT-8
- In 1982, Larry was elected a Fellow of IEEE for his work with acoustic waves (not lasers!)
- This work was very fabrication intensive, involving precision lithography and dry etching

APPLIED PHYSICS LETTERS VOLUME 18, NUMBER 8 15 APRIL 1971

MONOLITHIC ACOUSTIC SURFACE-WAVE AMPLIFIER*

L. A. Coldren
Stanford University, Stanford, California 94305
and
Bell Telephone Laboratories, Murray Hill, New Jersey 07974
and
G. S. Kino
Stanford University, Stanford, California 94305
(Received 29 December 1970; in final form 15 February 1971)

The characteristics of a monolithic surface-wave acoustic amplifier are described. Using indium antimonide vacuum-deposited on lithium niobate, electronic gain of 70 dB with a terminal gain of 24 dB has been obtained at 660 MHz.

598 PROCEEDINGS OF THE IEEE, VOL. 64, NO. 5, MAY 1976

Surface-Wave Long Delay Lines

LARRY A. COLDREN, MEMBER, IEEE, AND HERBERT J. SHAW, FELLOW, IEEE

PROCEEDINGS OF THE IEEE, VOL. 67, NO. 1, JANUARY 1979 147

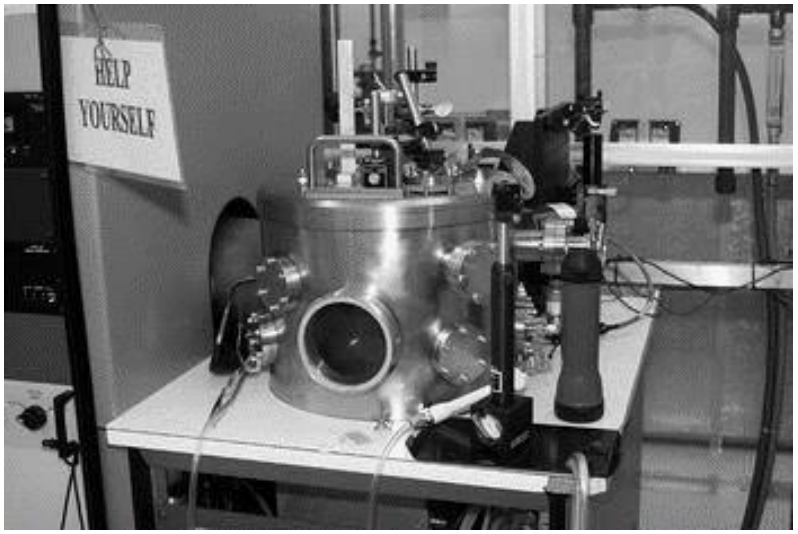
Surface-Acoustic-Wave Resonator Filters

LARRY A. COLDREN, SENIOR MEMBER, IEEE, AND ROBERT L. ROSENBERG, MEMBER, IEEE

Invited Paper

Getting into diode lasers

- A lot of work on growth of III-V materials and laser fabrication happening at Bell Labs
- Larry had an RIE system in his lab, and was a "processing guy"
- RIE etching of InP and III-V using chlorine – original work
- Having worked on acoustic filters, and etching slots, the idea was hatched – can we make a single mode (tunable) laser with coupled cavities? A PIC was born….



Directional reactive-ion-etching of InP with Cl_2 containing gases

L. A. Coldren and J. A. Rentschler

Bell Laboratories, Holmdel, N.J. 07733

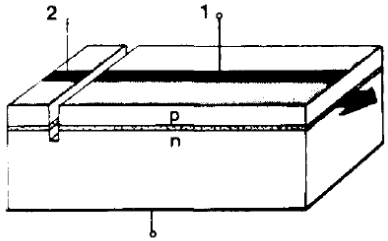
(Received 15 December 1980; accepted 14 April 1981)

Monolithic two-section GaInAsP/InP active-optical-resonator devices formed by reactive ion etching

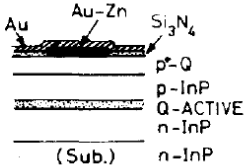
L. A. Coldren, B. I. Miller, K. Iga, and J. A. Rentschler

Bell Telephone Laboratories, Holmdel, New Jersey 07733

(Received 27 October 1980; accepted for publication 10 De

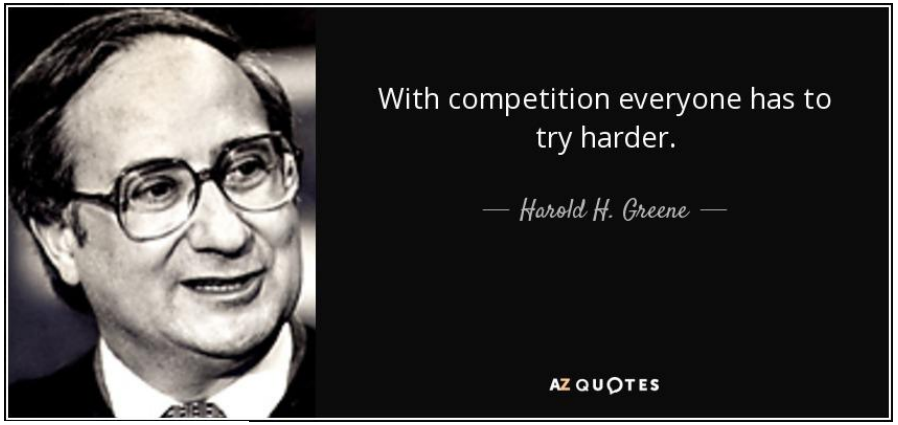


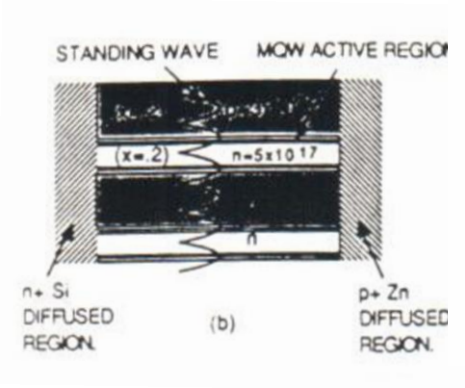
(a)

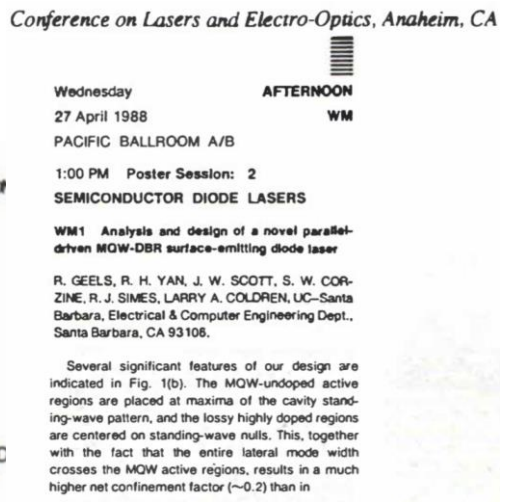


Move to UCSB and UCSB work

- 1982 breakup of AT&T brought the winds of change to Bell Labs
- Larry decided to pursue a career in academia
- Despite many choices, settled on UC Santa Barbara, an up-and-coming University, hoping to make it better (1984)
- Large investment and recruitment efforts at UCSB continued, fueled, in great part via SDI
- Larry was working on lasers, fabrication technology, and phase and other modulators
- Vertical resonant cavity modulator work led to a world changing idea that enabled commercialization of VCSELs (1987)
- Optical Concepts -> Gore Photonics







Conference on Lasers and Electro-Optics, Anaheim, CA

Wednesday AFTERNOON
27 April 1988 WM
PACIFIC BALLROOM A/B

1:00 PM Poster Session: 2
SEMICONDUCTOR DIODE LASERS

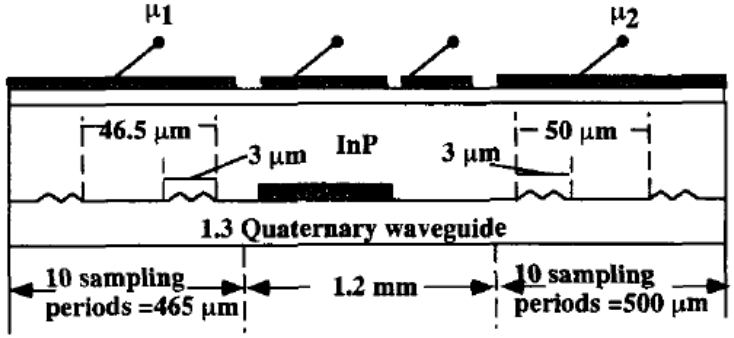
WM1 Analysis and design of a novel parallel-driven MQW-DBR surface-emitting diode laser

R. GEELS, R. H. YAN, J. W. SCOTT, S. W. CORZINE, R. J. SIMES, LARRY A. COLDREN, UC–Santa Barbara, Electrical & Computer Engineering Dept., Santa Barbara, CA 93106.

Several significant features of our design are indicated in Fig. 1(b). The MQW-undoped active regions are placed at maxima of the cavity standing-wave pattern, and the lossy highly doped regions are centered on standing-wave nulls. This, together with the fact that the entire lateral mode width crosses the MQW active regions, results in a much higher net confinement factor (~0.2) than in

Widely tunable lasers and PICs

- 1988 – patent on a multisection tunable laser with differing multi-element mirrors
  - Vernier effect for wide tuning
- Initial results – 3 section Vernier device
  - 1992, ISLC
- 4 section SGDBR laser – 1993



- Commercialization by Agility – 1998, acquisition by JDSU in 2005

United States Patent [19]
Coldren

[11] Patent Number: 4,896,325
[45] Date of Patent: Jan. 23, 1990

[54] MULTI-SECTION TUNABLE LASER WITH DIFFERING MULTI-ELEMENT MIRRORS

[75] Inventor: Larry A. Coldren, Santa Barbara, Calif.

[73] Assignee: The Regents of the University of California, Berkeley, Calif.

[21] Appl. No.: 235,307

[22] Filed: Aug. 23, 1988

[51] Int. Cl.[4] H01S 3/10
[52] U.S. Cl. 372/20; 372/99; 372/102; 372/38; 372/31; 372/29
[58] Field of Search 372/101, 20, 92, 99, 372/102, 29, 32, 38

[56] References Cited
U.S. PATENT DOCUMENTS

4,358,851 11/1982 Scifres et al. 372/6
4,504,950 3/1985 Au Yeung 373/101

OTHER PUBLICATIONS

Akiba et al.; "Self-Focusing Lens as Resonator enables 10 GHz Modulation"; Fiberoptic Technology Oct. 1981, p. 124.

Primary Examiner—Leon Scott, Jr.
Attorney, Agent, or Firm—Donald A. Streck

[57] ABSTRACT

An improvement for allowing selective tuning of the emitted beam over a broad bandwidth to a diode laser having an active section for creating a light beam by spontaneous emission over a bandwidth around some center frequency and for guiding and reflecting the light beam between a pair of mirrors bounding the active on respective ends thereof to create an emitted beam of laser light. The mirrors each have narrow, spaced reflective maxima with the spacing of the reflective maxima of respective ones of the mirrors being different whereby only one the reflective maxima of each of the mirrors can be in correspondence and thereby provide a low loss window at any time. The preferred mirrors each include a plurality of discontinuities to cause the narrow, spaced reflective maxima wherein the spacing of the discontinuities of one mirror is different from the spacing of the discontinuities of the other mirror so as to cause the wavelength spacing of the maxima to be different. Additionally, the preferred embodiment includes a vernier circuit operably connected to the mirrors for providing an electrical signal to the mirrors which will cause continuous tuning within a desired frequency band, an offset control circuit operably connected to the mirrors for providing a voltage signal to the mirrors which will shift the reflective maxima of the mirrors into alignment at a desired frequency mode, and a phase control circuit for adjusting the laser mode wavelength to be in correspondence with the low loss window.

27 Claims, 3 Drawing Sheets

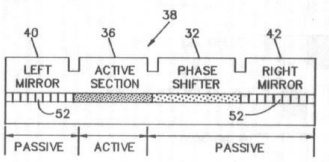


FIG. 5

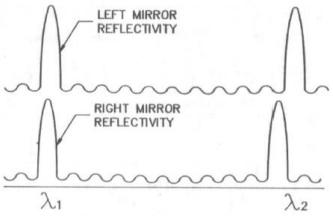
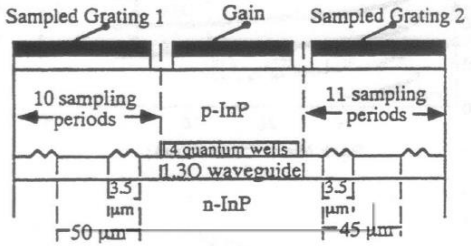
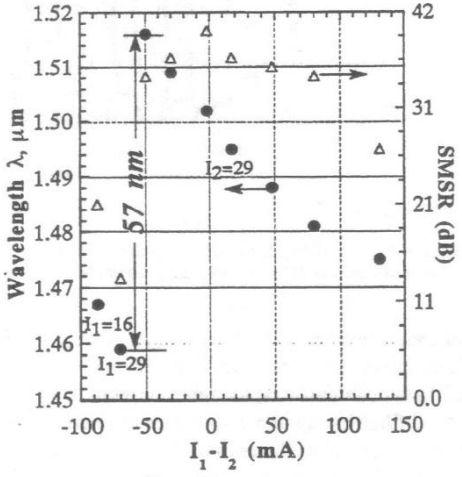
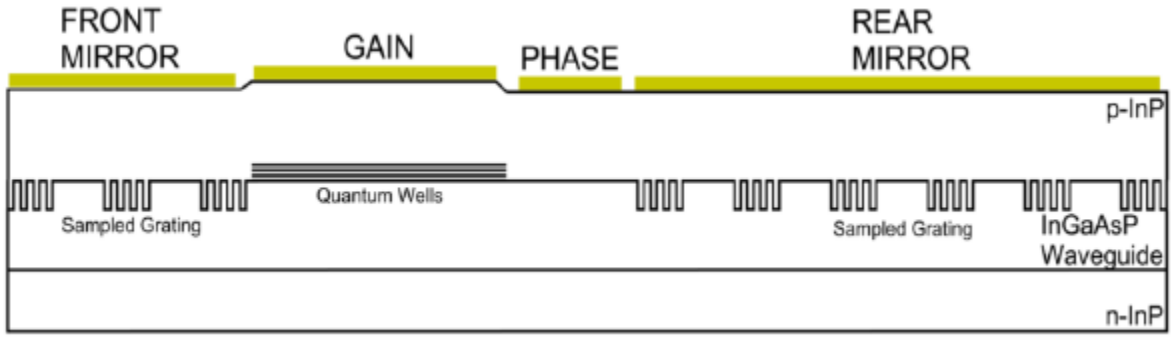


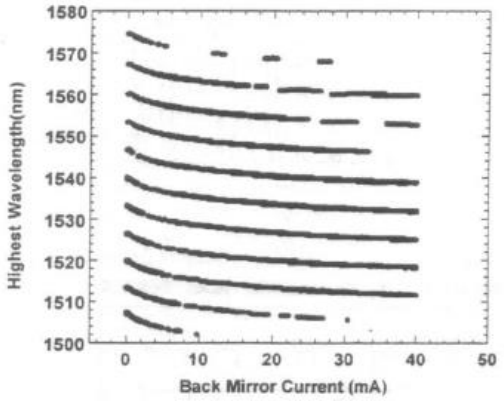
FIG. 7

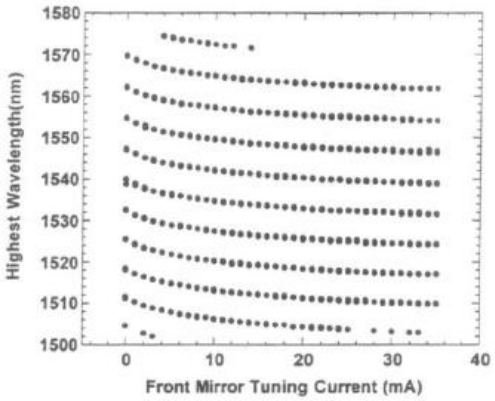


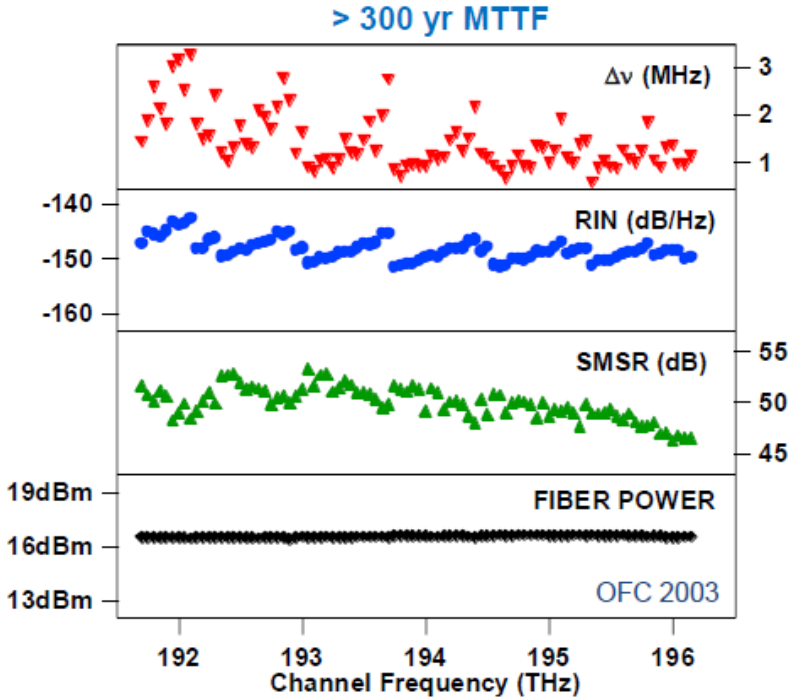


SGDBR – wide tuning, high power and reliability



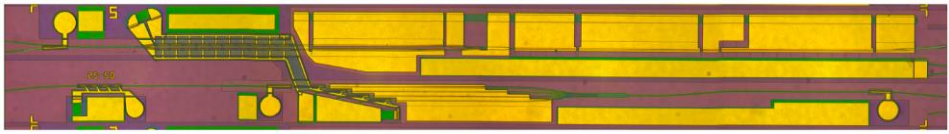






Photonic Integrated Circuit work at UCSB – SGDBR+ and *X devices

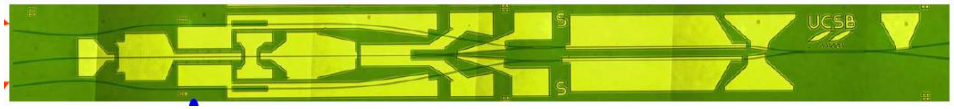
- EMLs, ILMZs, wavelength converters, coherent receivers,

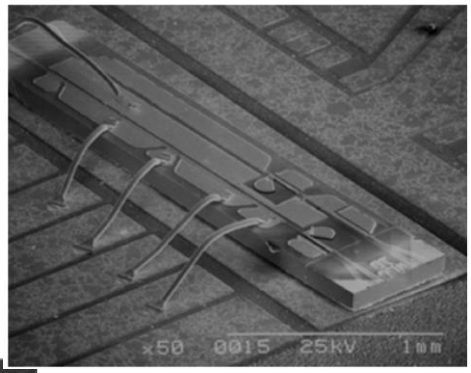


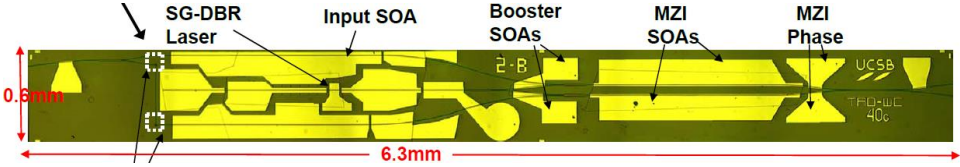
IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 11, NO. 6, JUNE 1999

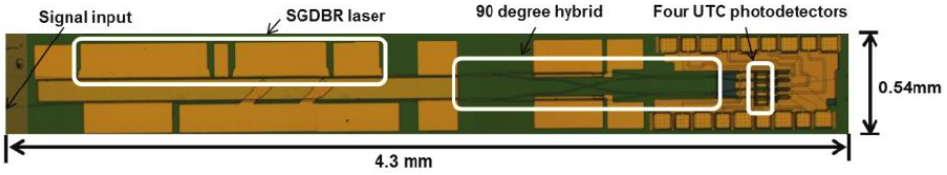
Widely Tunable Sampled Grating DBR Laser with Integrated Electroabsorption Modulator

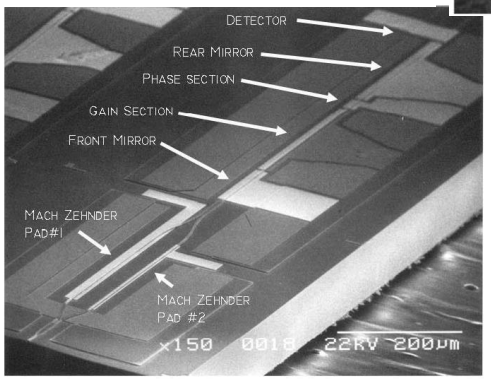
Beck Mason, Greg A. Fish, Steven P. DenBaars, and Larry A. Coldren, *Fellow, IEEE*

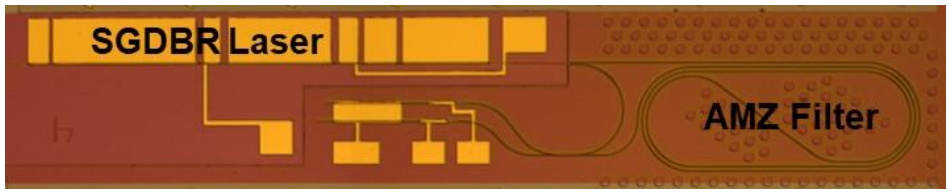




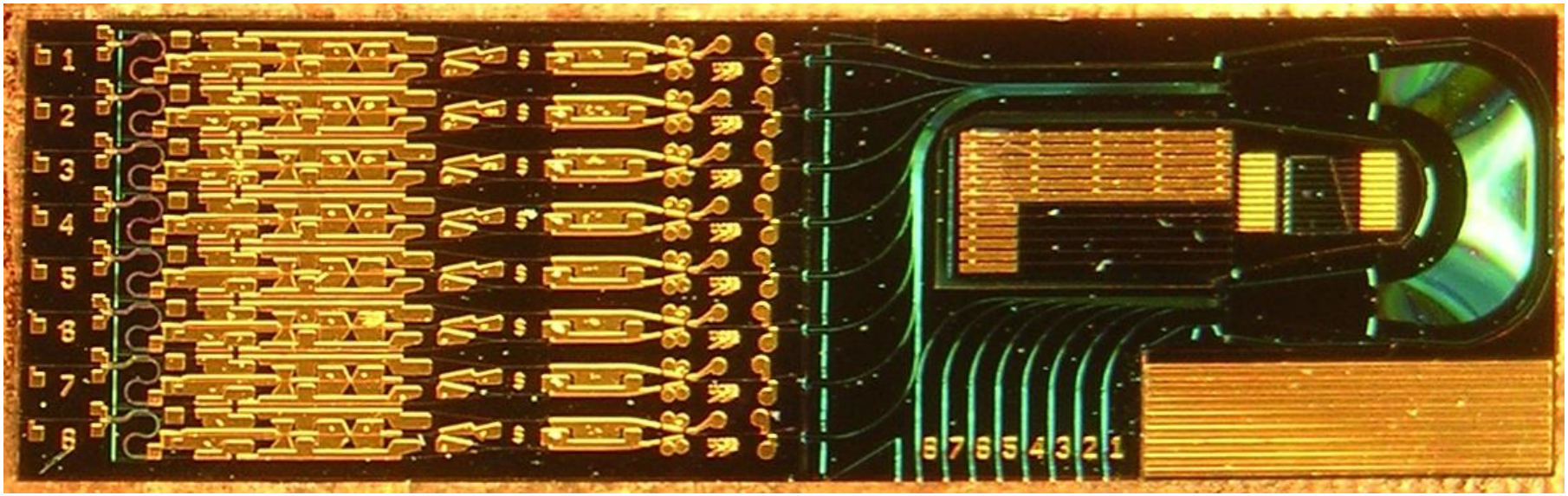


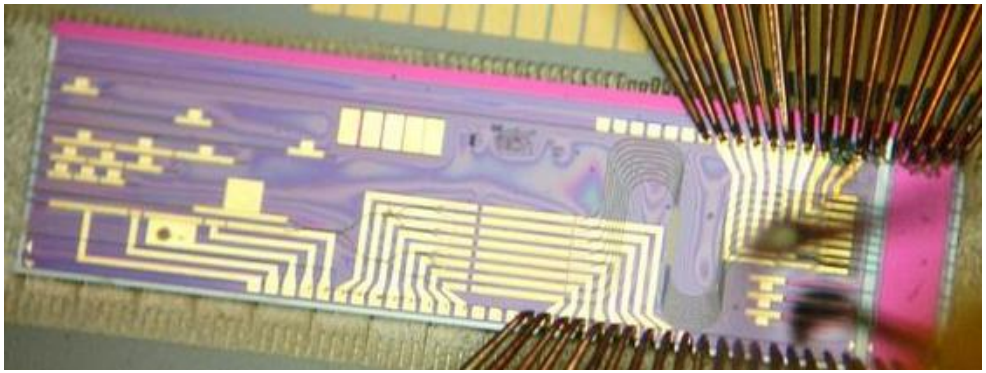


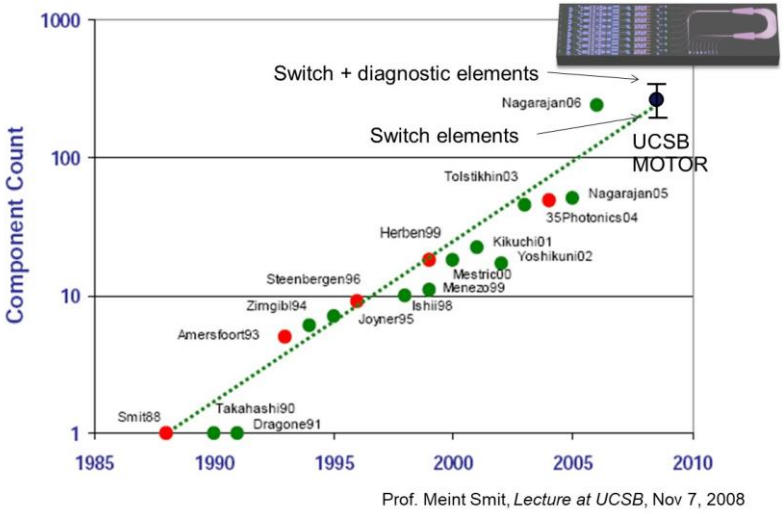




And large scale integration….







Prof. Meint Smit, *Lecture at UCSB*, Nov 7, 2008

The Book of Diode Lasers

- Standard textbook for graduate diode lasers and photonic integration circuit courses
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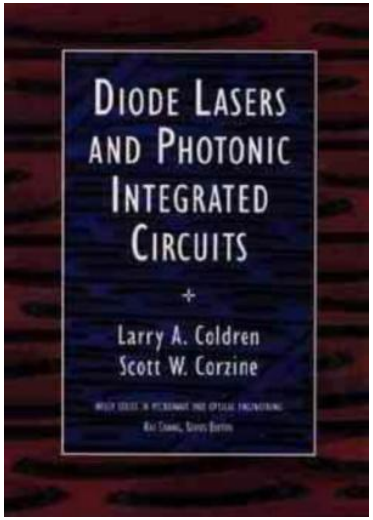

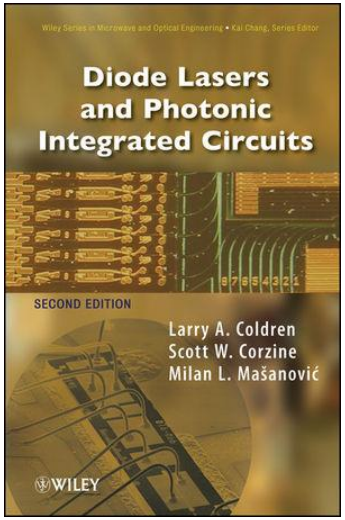

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997621	Larry A. Coldren, Scott W. Corzine, Milan L. Masanovic(auth.), Kai Chang(eds.)	Diode Lasers and Photonic Integrated Circuits, Second Edition *9780470484128, 9781118148167*		2012	72

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Tribute to the Career of Larry Coldren

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Freedom Photonics LLC