2016-9-14 ISLC Kobe

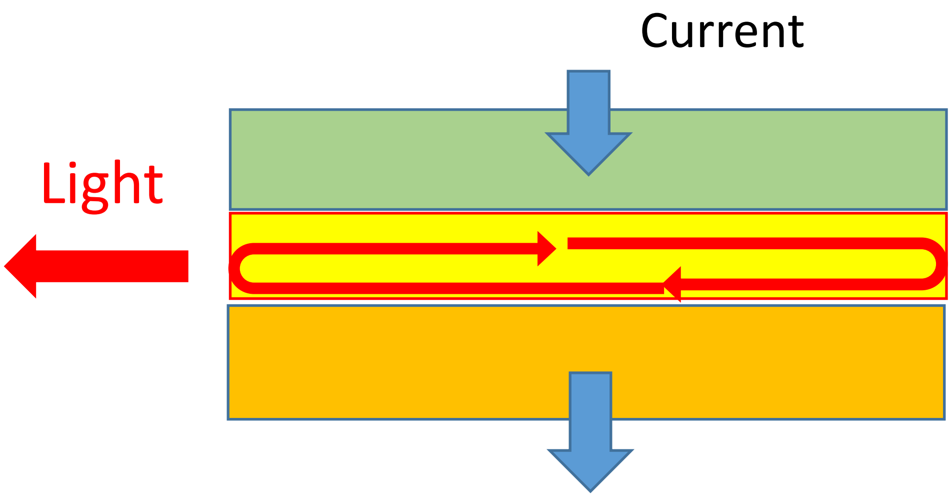
Dynamic Single Mode Lasers
saw
the Day of Light

Yashuaru Suematsu

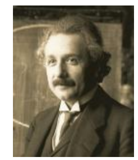
Honorary Professor,

Tokyo Institute of Technology

Semiconductor Laser *1962*



1962 US four Groups,
GaAs Semiconductor Lasers:
R. N. Hall etal, GaAs laser
M. I. Nathan etal, GaAs laser
T. M. Quist etal, GaAs laser
GaAsP Semiconductor Lasers:
N. Holonyak etal, GaAsP laser



1917 Albert Einstain

1953 Janos von Neumann

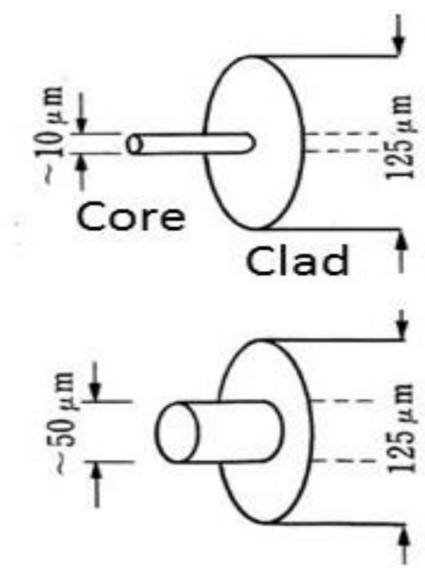
1958 Charles Townes

1960 Theodore Maiman

Cladded Optical Fiber *1953*

1868 James Clark Maxwell

1953 Abraham van Heel



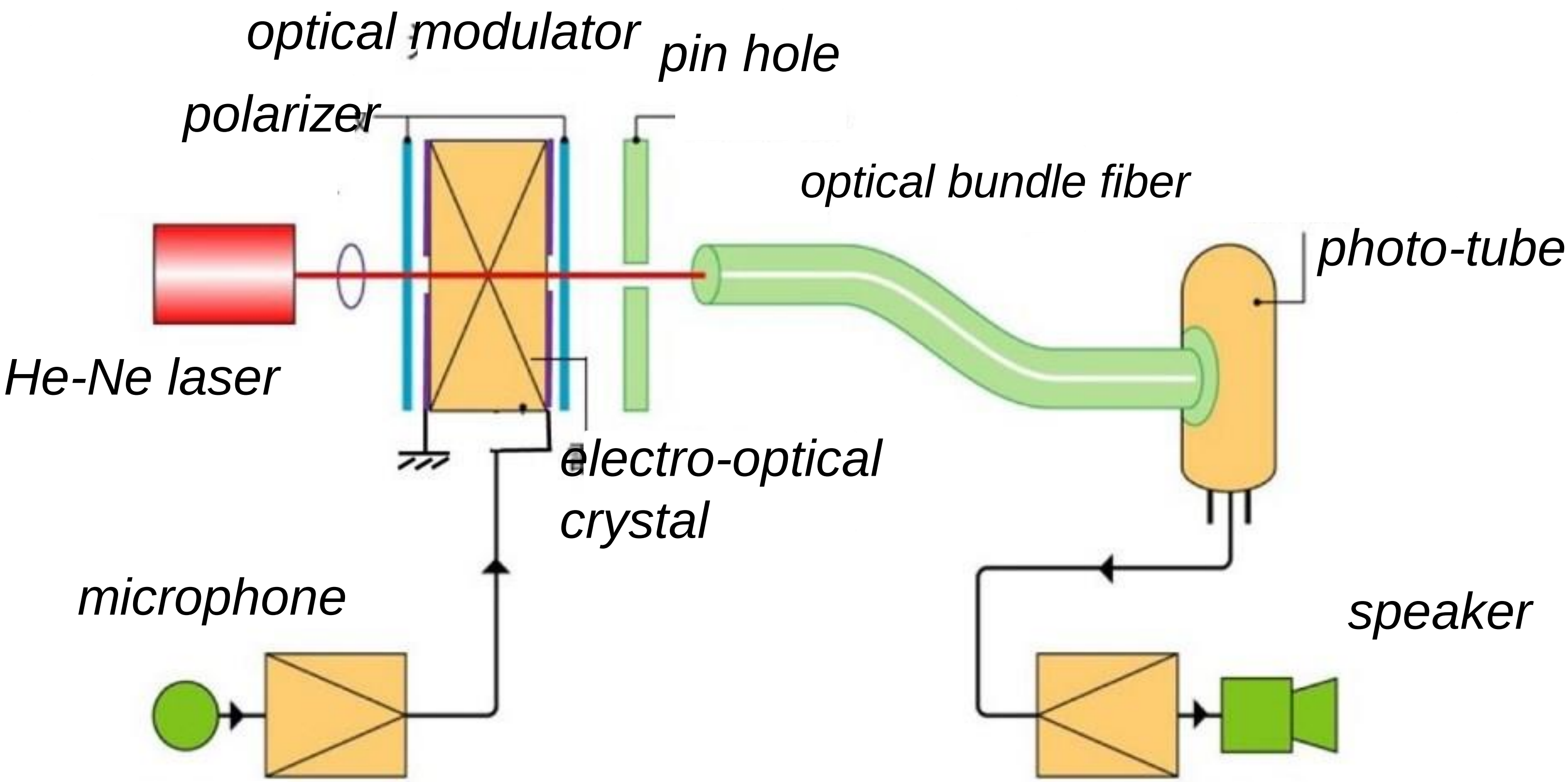
■Stance on my Research

System Oriented Device Research

on Optical Communications

Demonstration of Optical "Fiber" Communication

Toyo Institute of Technology, May 26, 1963



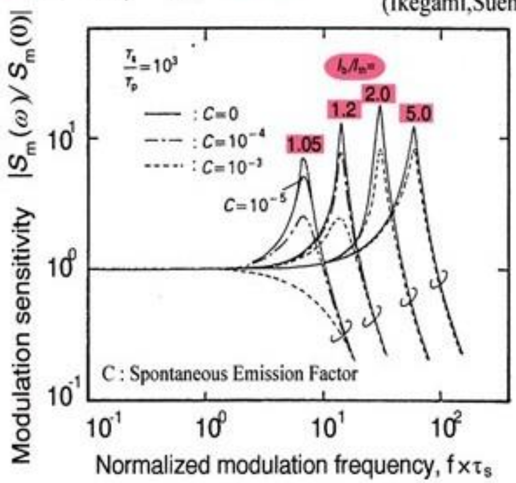
High Speed Direct Modulation of Semiconductor Lasers

The First
Semiconductor Laser Specialist Conference,
29th, November, 1967, Las Vegas, The Sands Hotel

$$\frac{S_m(\omega)}{S_m(0)} = \frac{1}{1+(\omega/\omega_{r0})^2 + j(\omega/\omega_{r0})(\Gamma/\omega_{r0})}$$

$$f_r = \frac{\omega_{r0}}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{(1-N_G/N_{th})}{\tau_p \tau_s}(I_b/I_{th}-1)}$$:Resonance-like Frequency

(Ikegami,Suematsu:T.I.T,1967)



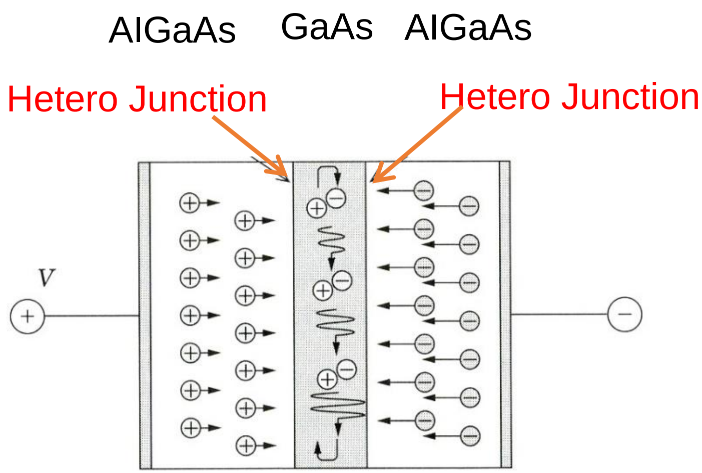
T. Ikgami and Y. Suematsu, 1967

Tetsuhiko Ikegami

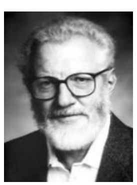
W. Susaki and Y. Suematsu

GaAlAs/GaAs Double Hetero-Structure Lasers

0.85μm, 1969-1970

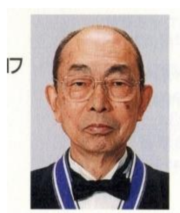


RT-CW Operation of GaAs/AlGaAs Doble Hetero-Structure Laser ***0.85μm*** *1969/1970*



1963 Herbert Kroemer (U California)
Hetero Junction

1969 Zhores Alferov (Yoffe Inst)
DH Laser

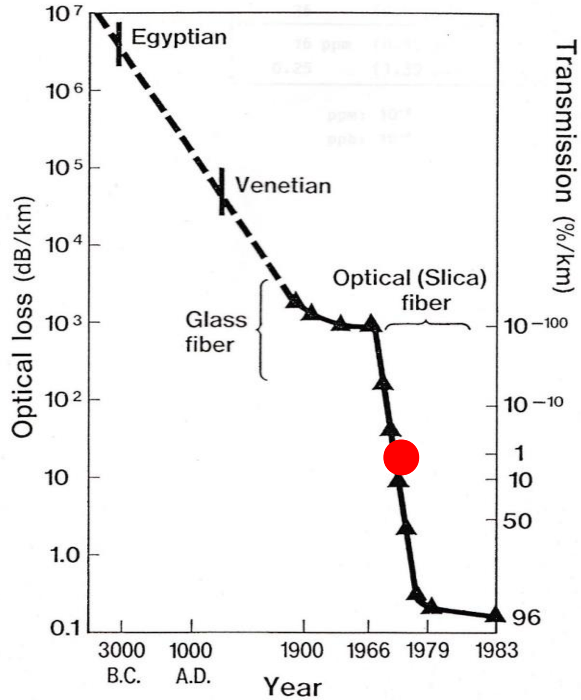


1970 Izuo Hayashi (BTL)
DH Laser

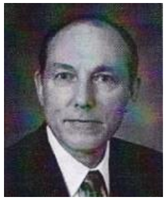
1970 orton . Panish (BTL)
DH Laser

Low Loss Silica Fiber

20db/km, 1970



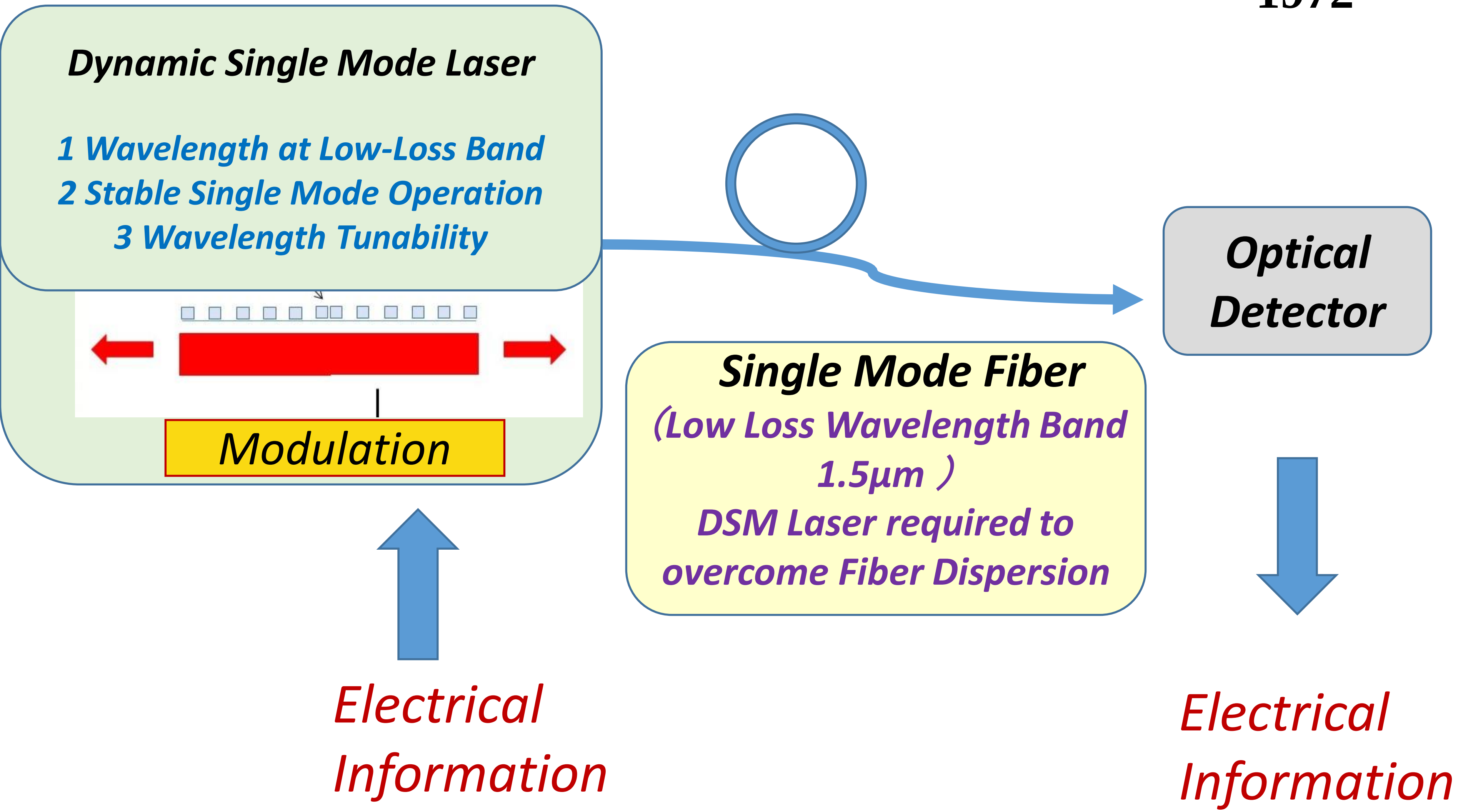
1966 Charles K. Kao
Proposal of Low Loss Fiber



1970 Robert . D. Maurer
CVD Fiber

Suggestion of Dynamic Single Mode (DSM) Lasers for Wide-Band and Long-Distance Optical Communication

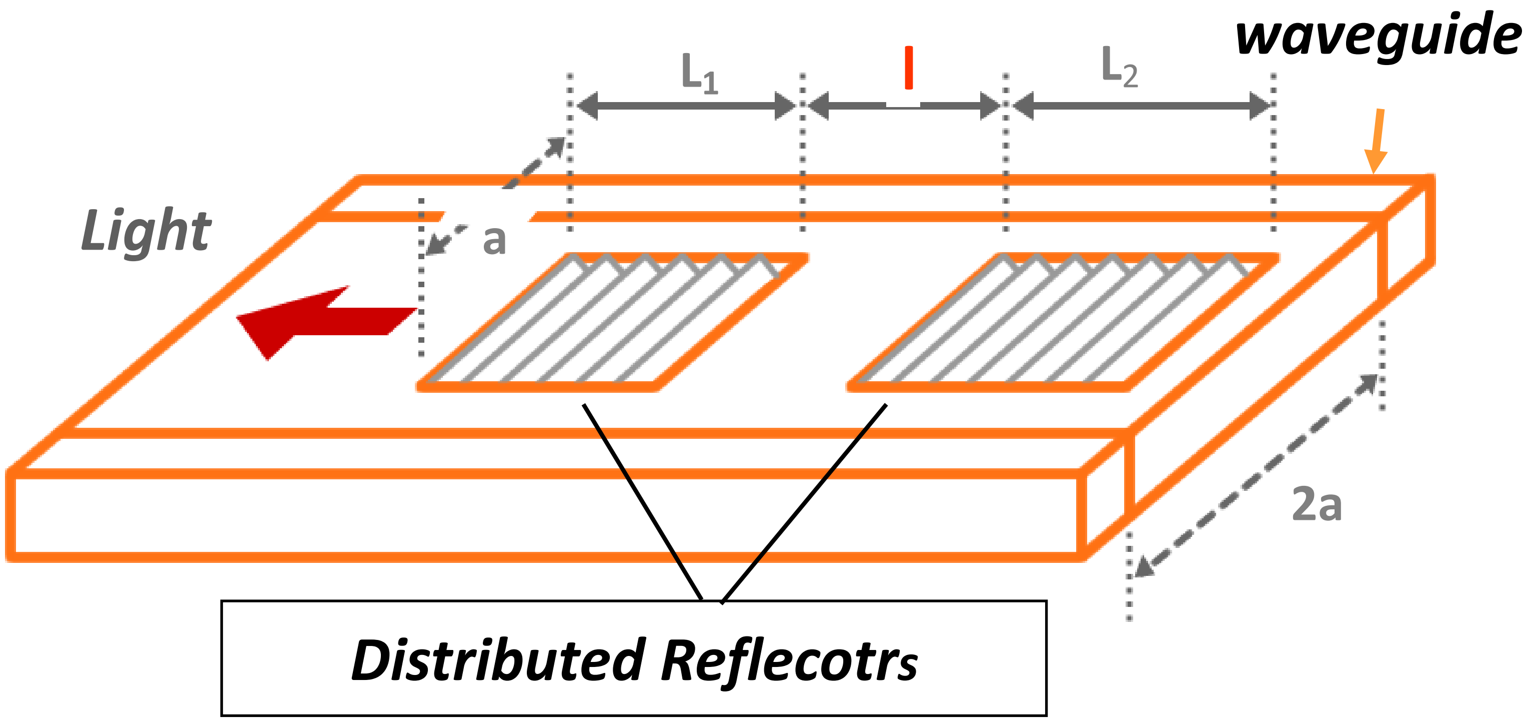
1972



Single Mode Resonator ~Two Distributed Reflectors connected by Separation of Odd Number Multiple of a Quarter Wavelength ~

Phase Shift "βl" between Two Distributed Reflectors

$$\beta l = (\pi/2)\, m \qquad (m : 1,3,5\ldots \text{Odd Number})$$



Kenji Hayashi

Y.Suematsu and K.Hayashi, National Convention of IECE,1200, July 1974.

■「中間で位相シフトした2分布共振反射器からなる単一モード共振器」の論文

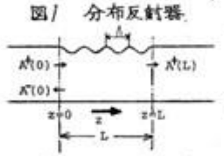
1200 分布反射器とこれを用いたレーザ共振回路の一般解析

末松安晴　林健二
(東京工業大学・工学部)

はしがき　分布帰還形(D.F.B.)のレーザは，将来の集積レーザの一つの形と考えられている。すでに，D.F.B.レーザの解析結果が報告されているが，二つの軸方向姿態の発振などの問題点があり[1]，必ずしも十分に性質が理解されていない。ここでは，分布反射器の性質を解析的に検討し，これを共振回路に応用する方法を提案し，分布反射器付共振回路の一般的解析を行った。

分布反射器の反射係数の解析　計算モデルとして図1のように膜厚が周期的に変化する構造を考え，$z=0$における電界の反射係数Rを求める。基本結合方程式は，

図1　分布反射器



$$-\frac{\partial}{\partial z}A^+(z)+\left(-\frac{\alpha}{2}-j\delta\right)A^+(z)=j\kappa A^-(z) \quad \cdots(1)$$

$$\frac{\partial}{\partial z}A^-(z)+\left(-\frac{\alpha}{2}-j\delta\right)A^-(z)=-j\kappa A^+(z) \quad \cdots(2)$$

となり[1]，$A^+(z)$は正のz方向へ進む電界の複素振幅，$A^-(z)$は逆方向へのものである。αは電力損失定数，δは発振周波数とπ/Λとの差$\delta=\beta-\pi/\Lambda=\beta-\beta_0$（一次回折反射），$\kappa$は結合定数である。式(1)，(2)の解は

$$A^+(z)=a_1^+e^{\gamma z}+a_2^+e^{-\gamma z} \quad \cdots(3)$$

$$A^-(z)=a_2^-e^{\gamma z}+a_1^-e^{-\gamma z} \quad \cdots(4)$$

となる。$\gamma^2=\kappa^2+(\alpha/2+j\delta)^2$　まず$\alpha=0$として損失を考えない。$z=0$とLにおける境界条件から，電界の反射として

$$R=\frac{A^-(0)}{A^+(0)}=\frac{a_1^-+a_2^-}{a_1^++a_2^+}=\frac{-j\kappa}{\gamma\coth(\gamma L)+j\delta}=|R|e^{j\varphi} \quad \cdots(5)$$

が得られる。ここに，$\gamma^2=\kappa^2-\delta^2$

$$|R|^2=\frac{(\kappa L)^2}{(\gamma L)^2\coth^2(\gamma L)+(\delta L)^2}\ (\text{電力反射率}) \quad \cdots(6)$$

$$\varphi=-\frac{\pi}{2}-\tan^{-1}\left\{\frac{\delta L}{\gamma L}\tanh(\gamma L)\right\} \quad \cdots(7)$$

$\kappa L=1,2$とした場合について，$|R|^2$のグラフを示す。（図2）次に損失を考慮した時の$\delta L=0$における電力反射率$|R|^2$は，

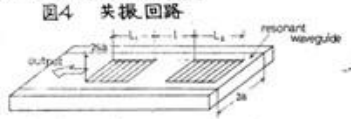
$$|R|^2=\left[\frac{1}{\{\gamma L\coth(\gamma L)\}/\kappa L+(\alpha L/2\kappa L)}\right]^2 \quad \cdots(8)$$

$$\gamma^2=\kappa^2+(\alpha^2/4)$$

$\alpha L/\kappa L$をパラメータとした$|R|^2$とκLの関係を示す。（図3）

共振条件　図4のように長さL_1，L_2の分布反射器を両側におき，その間に長さℓの活性領域が存在する構造を考えよう。

図4　共振回路



この時，共振条件は，$\varphi_1+\varphi_2+2\beta\ell=2m\pi$ ―(9)
となる。$L_2=2L_1$，$2\beta\ell=2M\pi+\varphi_0$，$\varphi_0=\pi$，$\ell=L_1$，$m-M=p$とおけば，式(9)は式(7)より，

$$2\delta L_1-2p\pi-\tan^{-1}[\{\delta L_1\cdot\tanh(\gamma L_1)\}/(\gamma L_1)]-\tan^{-1}[\{\delta L_1\cdot\tanh(2\gamma L_1)\}/(\gamma L_1)]=0 \quad \cdots(10)$$

$\kappa L_1=1$の場合について，上の共振条件を満たすδL_1は軸モード　$p=0$で$\delta L_1=0$，1.22
$p=1$で$\delta L_1=3.5$

となる。上述のδL_1における電力反射率はそれぞれ58%，45%，0.4%である。ポンピングレベルを加減して，反射率50%以上が発振するようにすれば，軸方向単一姿態発振が$\varphi_0=\pi$で可能になる。横姿態は分布反射器の幅を図4で約$s=1/2$にとると，横姿態差による損失差が大きく，単一基本姿態となる。

むすび　分布反射器を純然たる反射器と考えて，反射係数の一般解法を示し，これを応用して，D.F.B.レーザでも軸方向単一姿態発振が得られることと，分布反射器の幅で横方向単一基本姿態が得られることを示した。

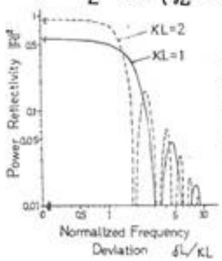


図2　電力反射率と規格化発振周波数との関係

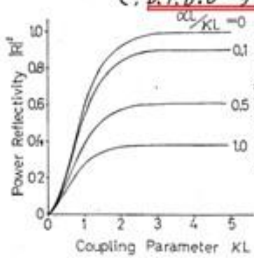


図3　電力反射率と結合パラメータとの関係

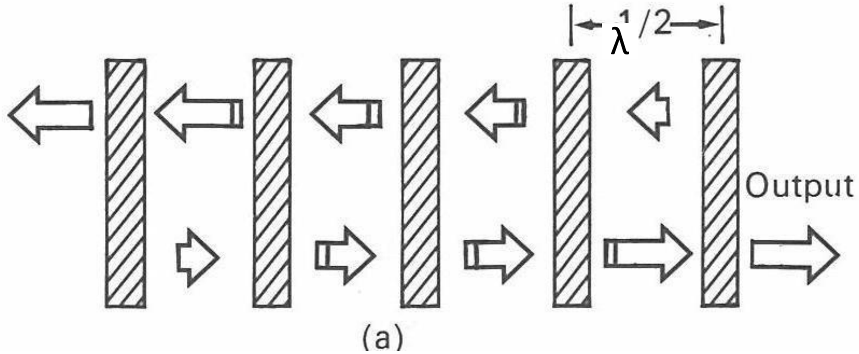
謝辞　本研究は文部省科学研究費の補助を受けた。

文献　1) H. Kogelnik, C.V. Shank "Coupled-Wave Theory of Distributed Feedback Lasers" J. Appl. Phys. 43 2327 (1972)

40759

英訳論文名:
"General analysis of distributed Bragg reflector and laser resonator using it",
Yasuharu Suematsu and Kenji Hayashi,
National Convention of the Institute of Electronics and Communication Engineer,
1200, p.1203, July 25-27, 1974.

H. Kogelnik and C. V. Shank , "Coupled wave theory of distributed feedback（DFB）Lasers," J. Appl. Phys. Vol. 43, no. 5, pp. 2327-2335, May 1972



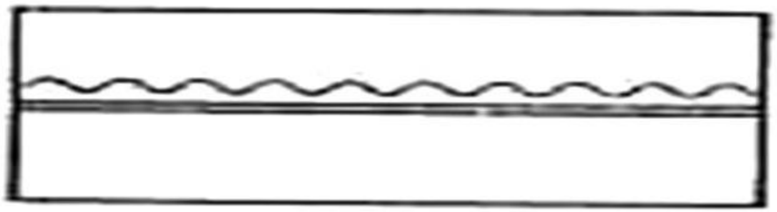
Herwig Kogelnik (BTL)

Charles Shank (BTL)

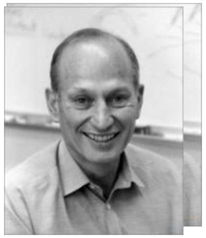
Two Modes Operation

（for Refractive Index Coupling with Uniform distributed Reflector）

M. Nakamura, A. Yariv, H. W. Yen, S. Somekh, and H. I. Garvin, "Optically pumped GsAS surface laser with corrugation feedback, " Appl. Phys. Lett., vol. 22, no. 10, p. 515, May 1973.



Michiharu Nakamura (CALTEC)

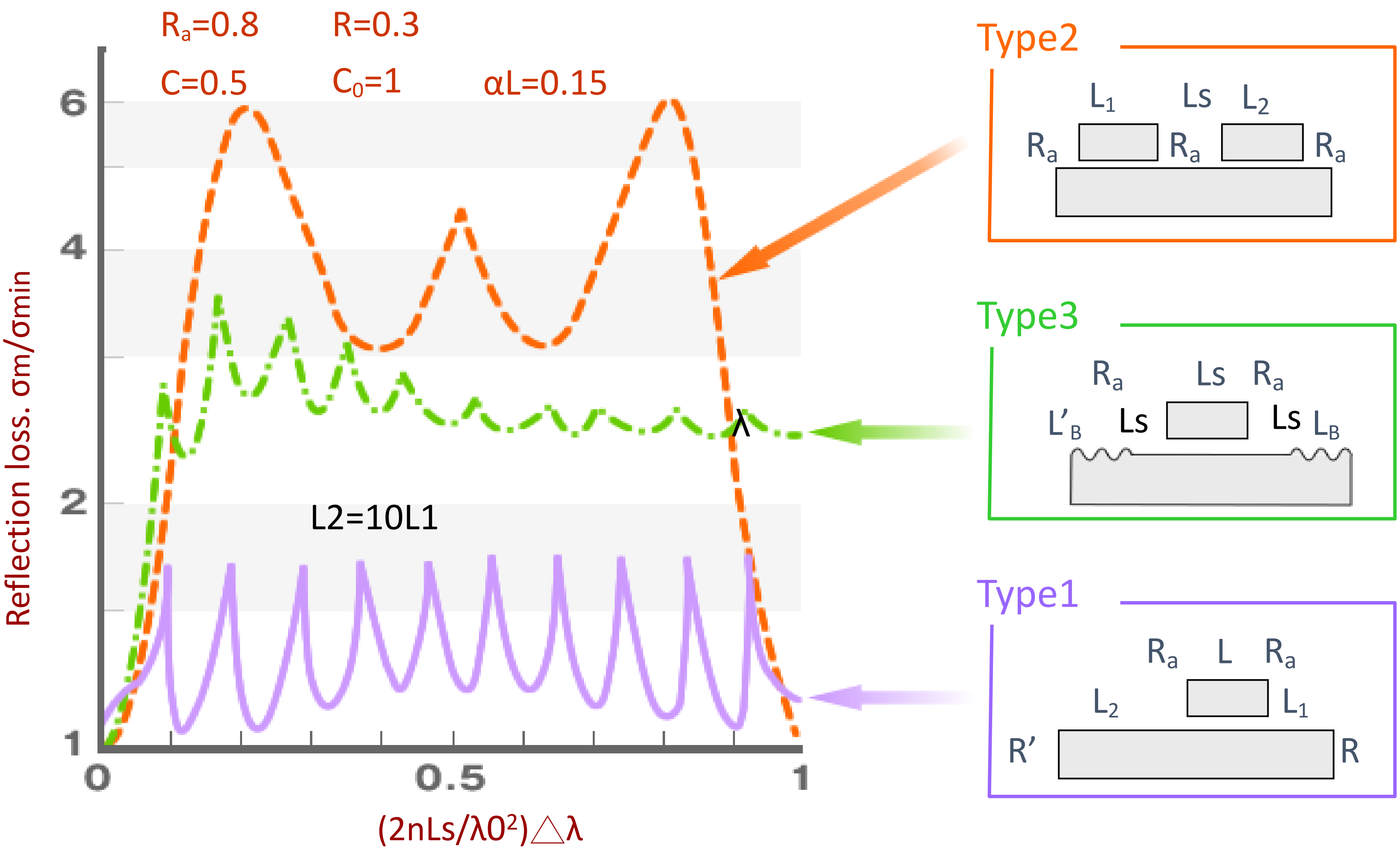


Amnon Yariv (CALTEC)

Semiconductor DFB Laser

Sharp mode selectivity

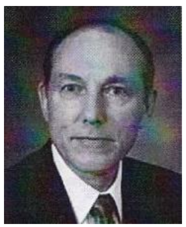
■ Mode Selectivity of ITG Lasers



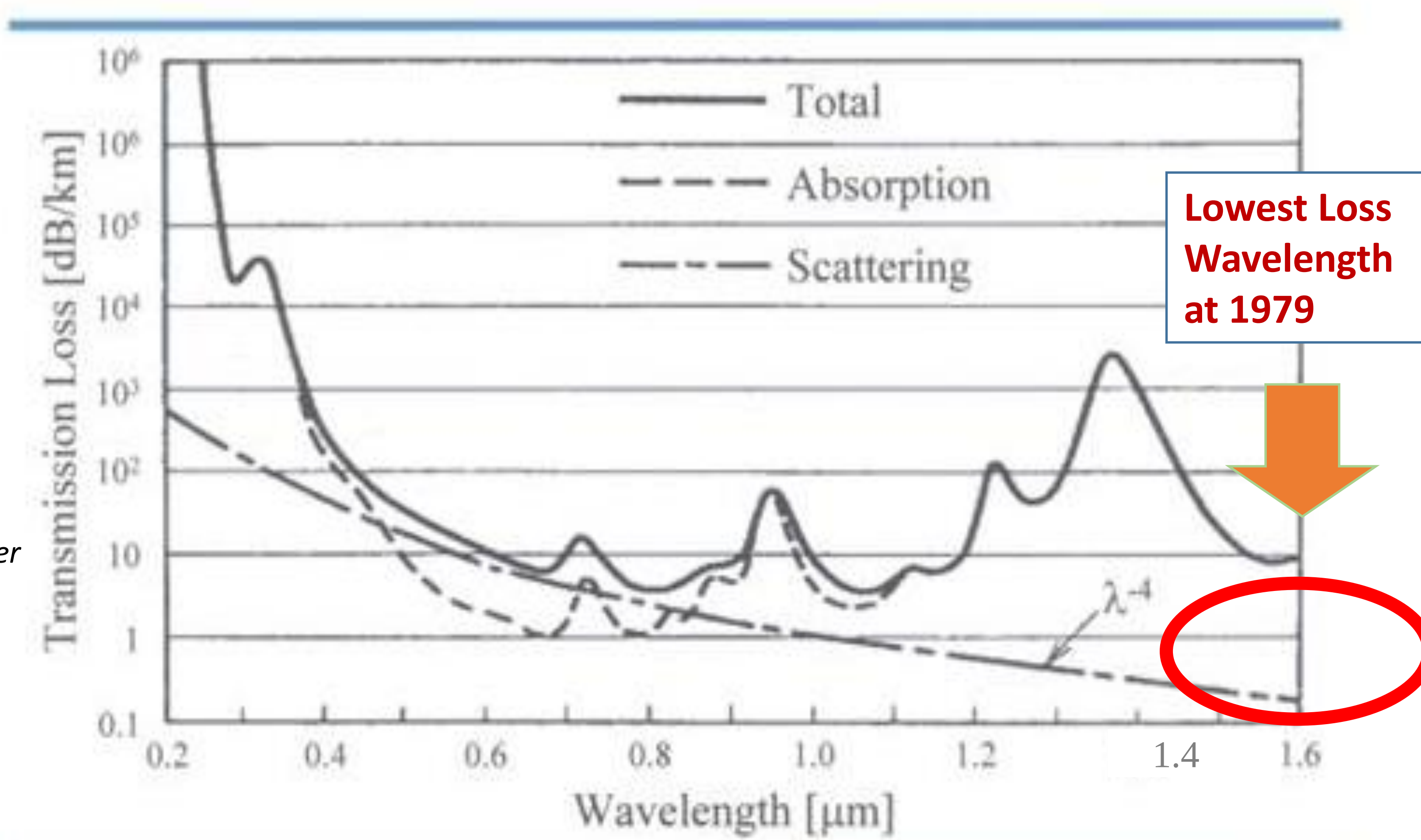
Y.Suematsu, K.Kishino, and T.Kambayashi, IEEE J. Quantum Electron., Vol.QE-13, No.8, Aug. 1977

Suggestion of Possible Lower Loss at Longer Wavelength

1973
Donald Keck



1973
Robert Maurer

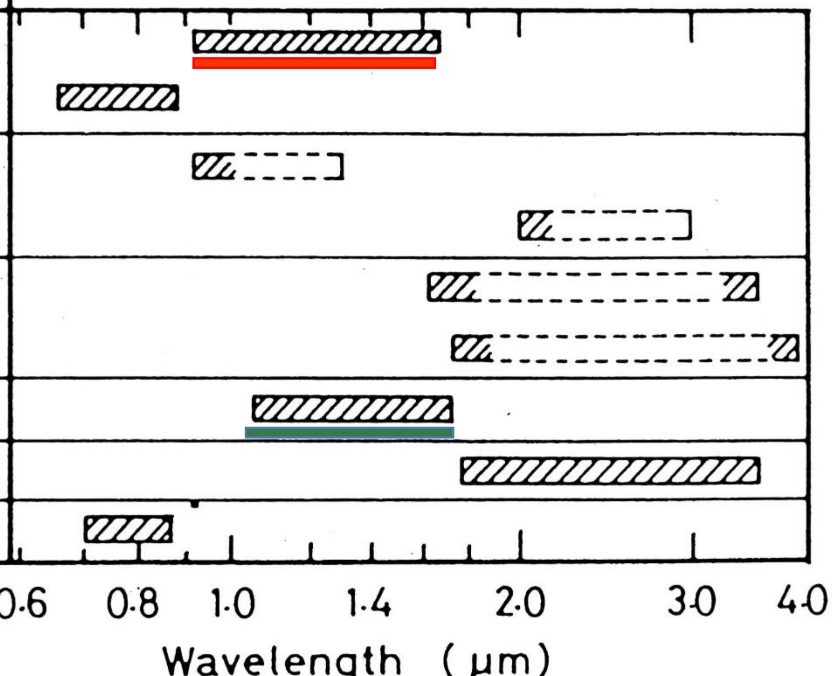


By D.B. Keck, R.D. Maurer, & P.C. Schultz. 1973

Possible Material Systems for Possible Long Wavelength Lasers at Low-Loss Band of Fuyure Fiber

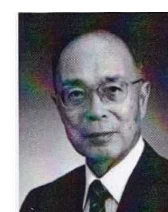
Jim Hsieh (MIT)

Active Material	Substrate Mater.	Melt. P. (°C)	Hardness (Knoop)
GaInAsP	InP	1070	535
	GaAs	1238	750
GaInSbP	InP	1070	535
	GaSb	712	450
GaInAsSb	InAs	943	381
	GaSb	712	450
AlGaAsSb	GaSb	712	450
InAsSbP	InAs	943	381
AlGaAs	GaAs	1238	750



Yoshio Itaya

(100) Oriented InP Substrate



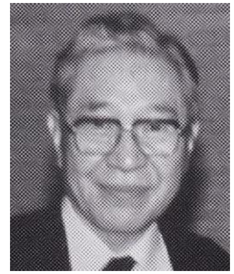
Kenichi Iga

Partly by Moon, Antypas, and James, 1974

Supports in DSM Laser Research of Expensive Work

Masamitsu Kawakami
President of Tokyo Tech.

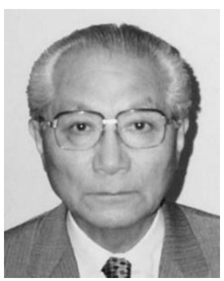
Teiichi Yamazaki
President of TDK



Yukio Nakagome
Director-G
KDD Research Lab.

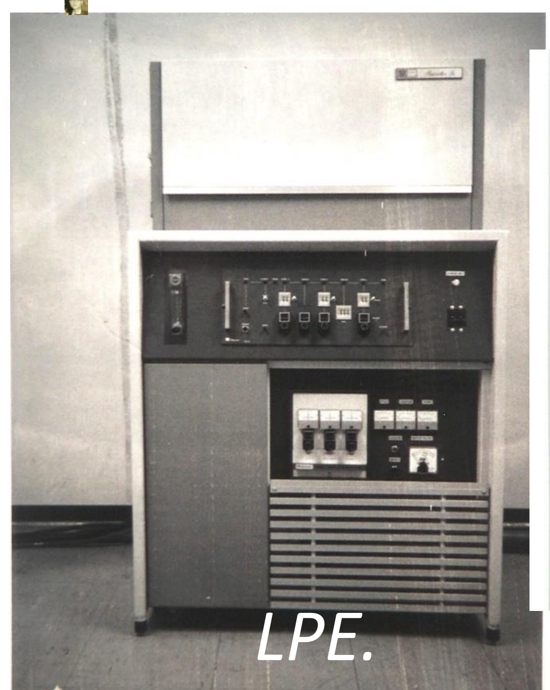
Ministry of Education

Genya Kishi
Professor
Tokyo Tech.

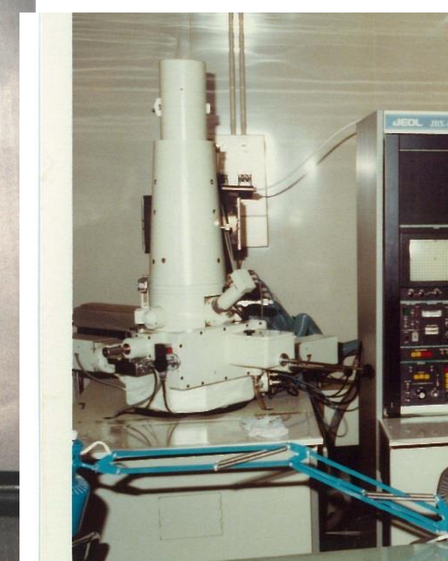


Kunihiro
Suetake
Professor
Tokyo Tech.

Shigebumi Saito
Professor
Univ. Tokyo



LPE.



EBX.

■1.5μm Band GaInAsP/InP Lasers and Fiber Loss

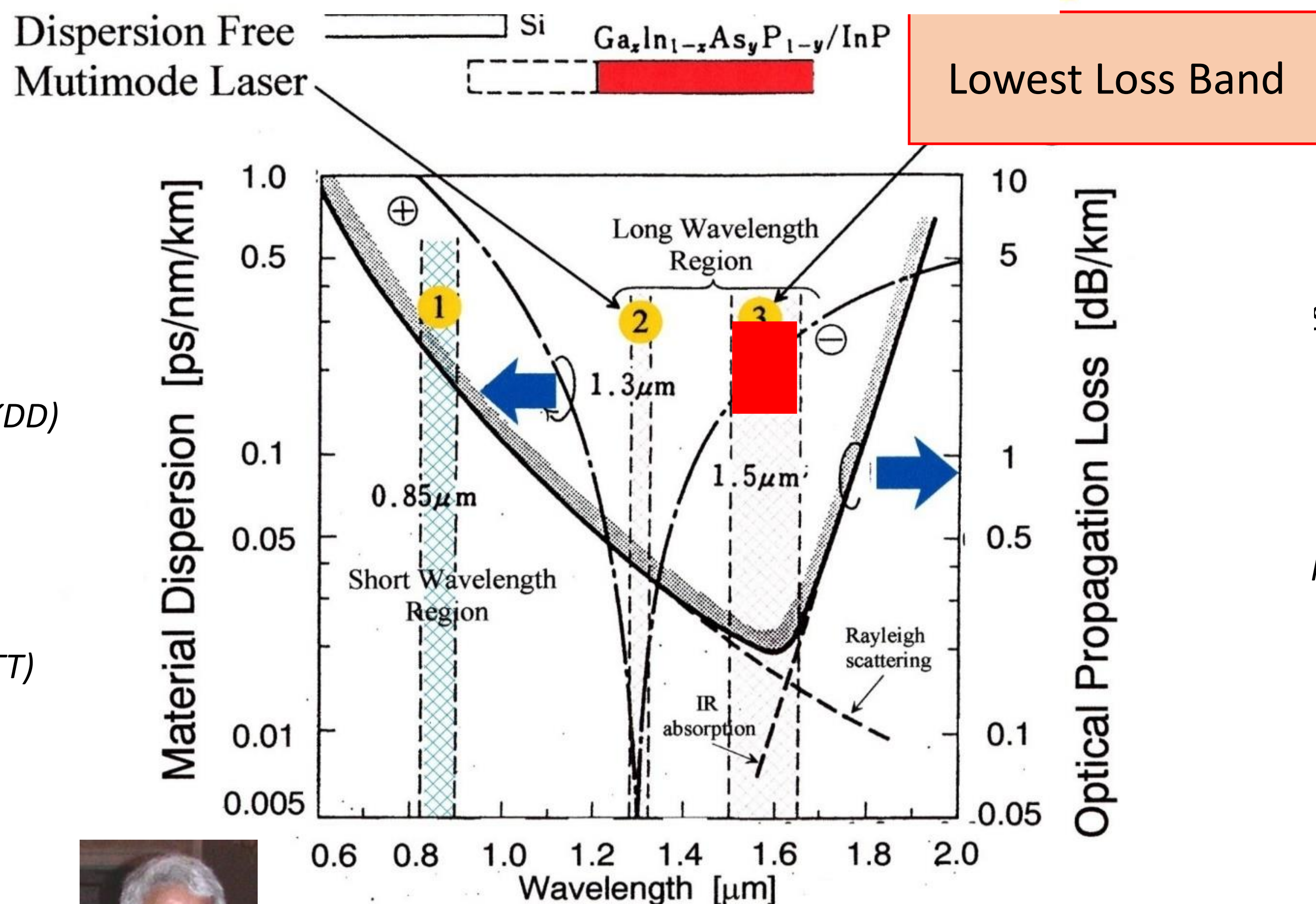
RT-CW Operation of 1.5 μm GaInAsP/IP Laser by
S. Arai, M. Asada, Y. Suematsu, & Y. Itaya, 1979.

Shigehisa Akibaa (KDD)

Hitoshi Kawaguchi (NTT)

Ivan Kaminow (BTL))

Tadashi Miyashita (NTT)



Fiber Data by T.Miya,Y.Terunuma,
T.Hosaka & T.Miyashita, 1979

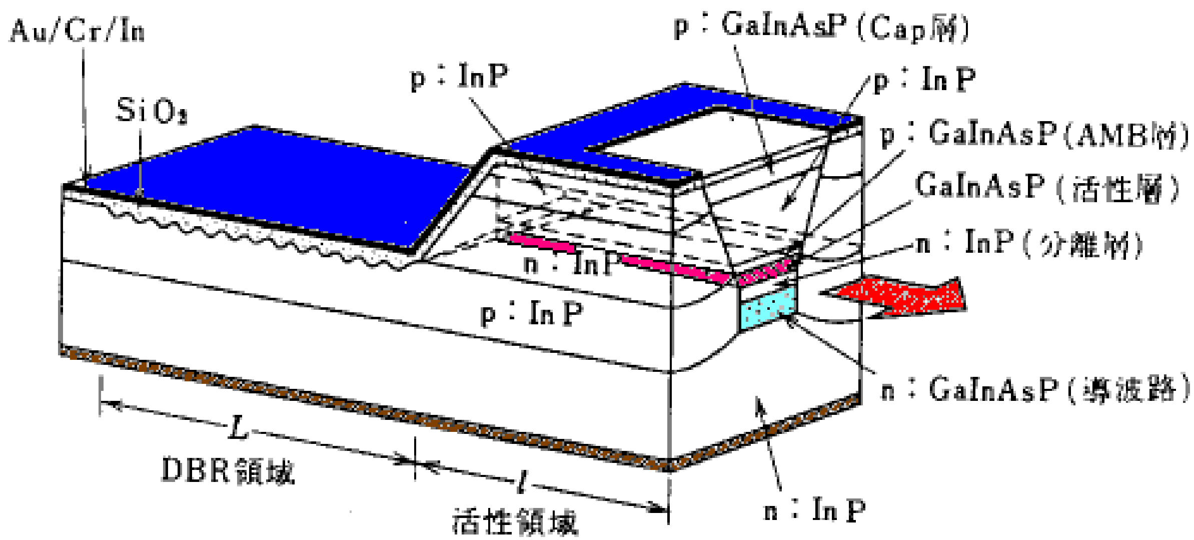
Shigehisa Arai

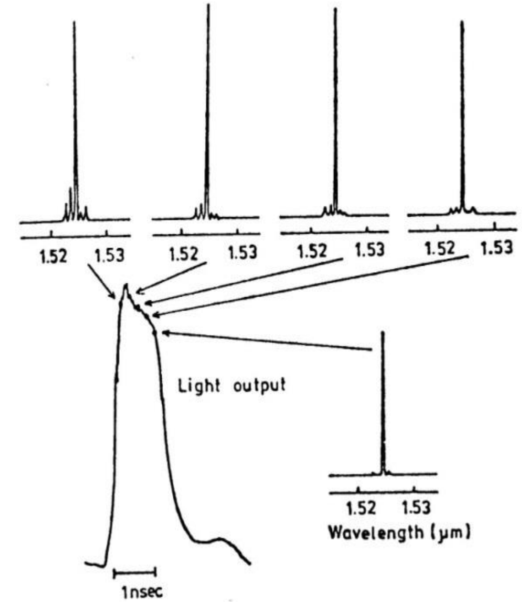
Masahiro Asada

Yoshio Itaya

Katsumi Kishino

Ⅳ Demonstration of Dynamic Single Mode Lasers 1.5μm Band





K. Utaka, K. Kobayashi and Y. Suematsu 1981

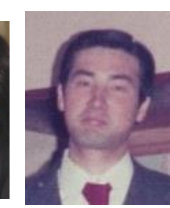






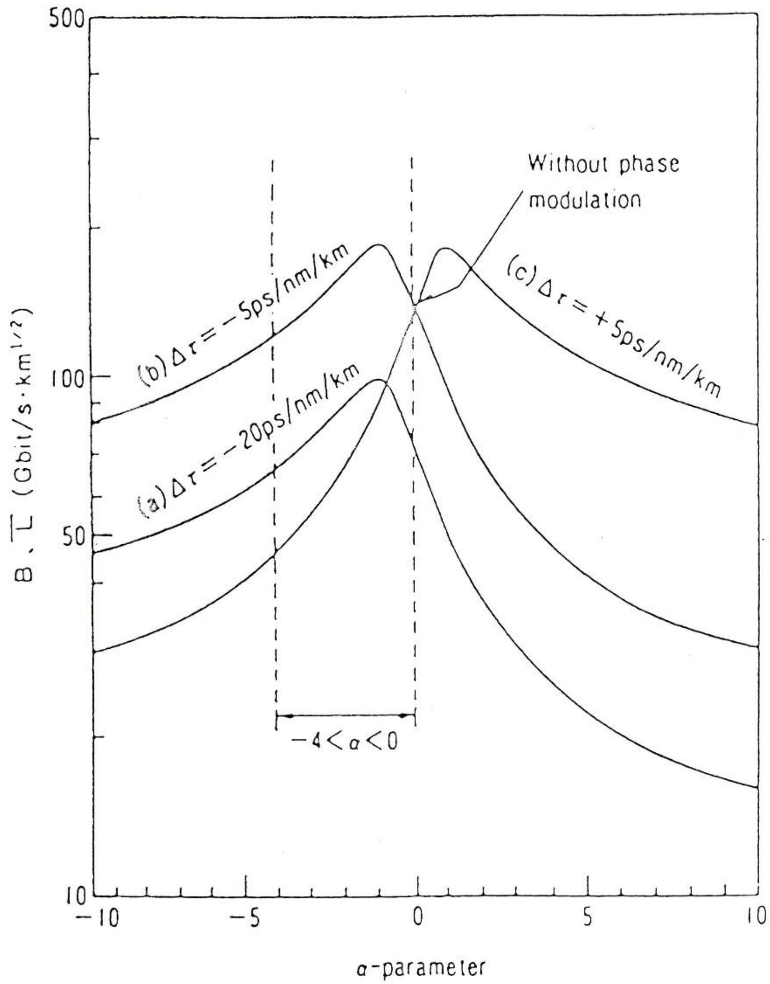






Katsuyuki Utaka | Kennji Kobayashi | Hideo Kawanishi | Fumio Koyama | Katsumi Kishino | Yuhji Abe | Taui Tanbun-EK | *Yoshio Itaya* | *Shigehisa Arai* | Kazuhiro Komori | Yasushi Sakakibara

IV Dynamic Spectral Width and Transmission Bandwidth



F. Koyama and Y. Suematsu, IEEE J. Quantum Electron, Apr. 1985.

α : linewidth enhancement factor

Fumio Koyama

Katsumi Kishino

Masahiro Asada

Thomas Koch (BTL)

Yasuyuki Miyamoto

Yasunari Miyake

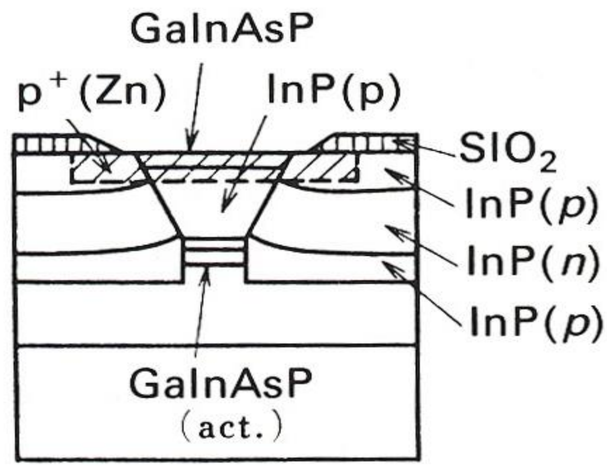
Buried Hetero Structure (BH) InGaAsP/InP Laser: *Single Transverse Mode Operation*

T. Tsukada,"GaAs-$Ga_{1-x}Al_xAs$ buried heterostructure injection lasers,",*J. Appl. Phys.*, vol. 45, no. 11, Nov. 1974.

Naoki Chinone,
(HITACHI)

Ikuo Mito
(NEC)

Kourou Kobayashi
(NEC)



(a) Buried hetero structure laser (BH).

Toshihisa Tsukada
(HITACHI)

Hiroshi Ishikawa
(FUJITSU)

Hajime Imai
(FUJITSU)

Yoshio Itaya
1.6μm

Katsumi Kishino

Phase Shift Distributed Reflector Laser

1984-1985

~ Thermo-Tunable DSM Laser ~

Fumio Koyama

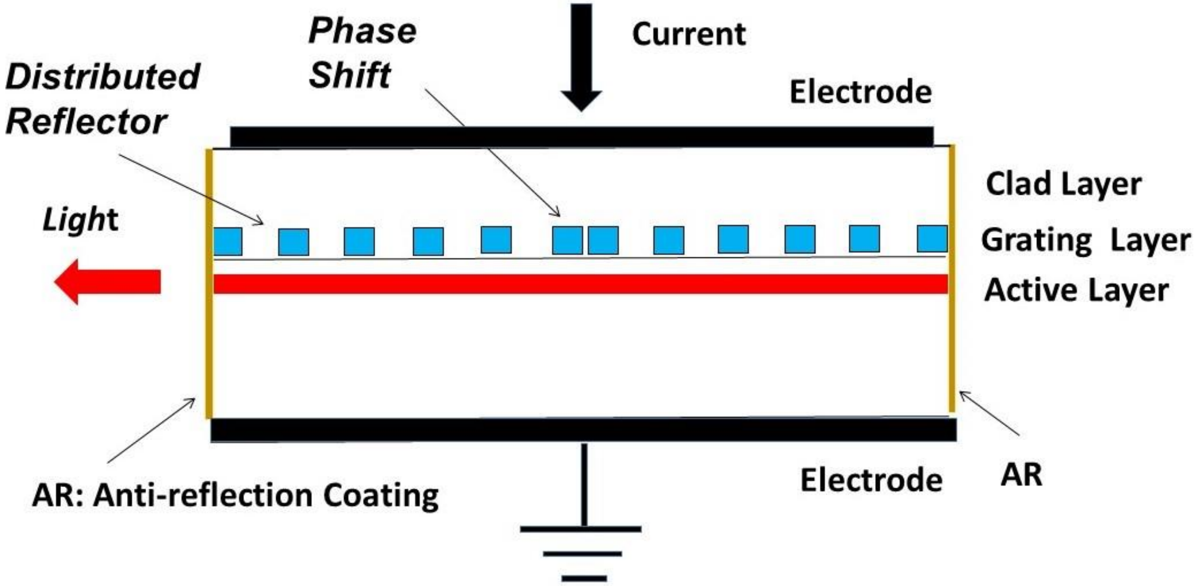
Taui
Tanbun-EK

High Yield of Production
due to Built in Single Mode Resonator

Kazuhito Furuya

Sekartejo Kunchoro

Norikazu Eda



Katsuyuki Utaka
(KDD) 1985

Shigeyuki Akiba
(KDD) 1985

K. Sakai
(KDD) 1985

K. Sekartedjo, N. Eda, K. Furuya,
Y. Suematsu, F. Koyama, & Tanbun-Ek, 1984
K. Utaka, S. Akiba, and K. Sakai, 1985

Demonstration of Phase-Sift Distributed Feedback Laser

1984

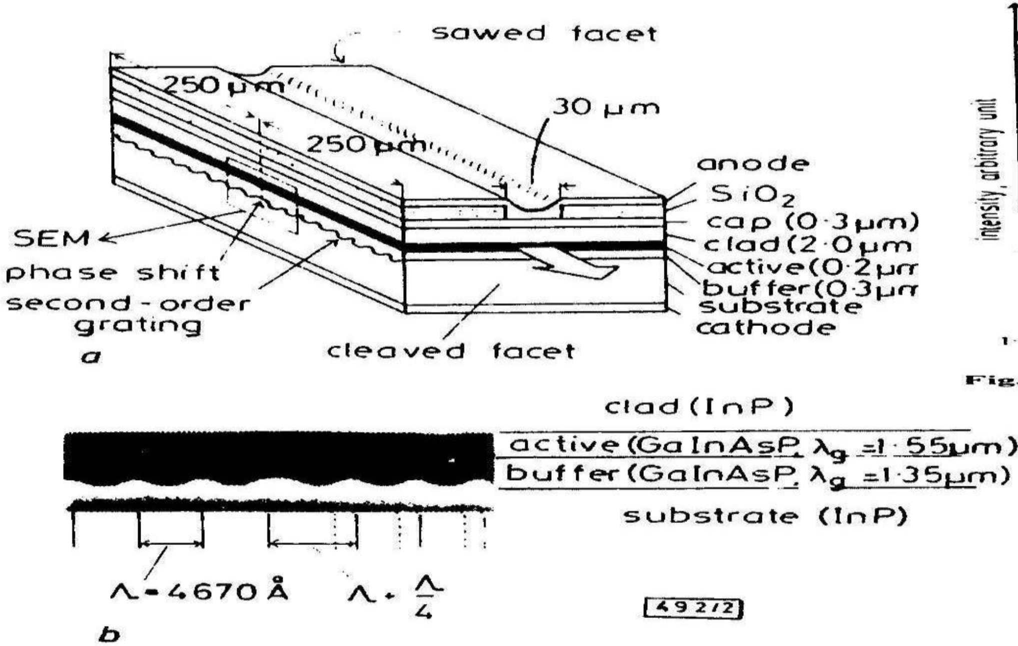


Fig. 2 *Phase-shifted DFB laser*
a Schematic representation of structure
b Cross-sectional SEM view of part where phase of corrugation is shifted

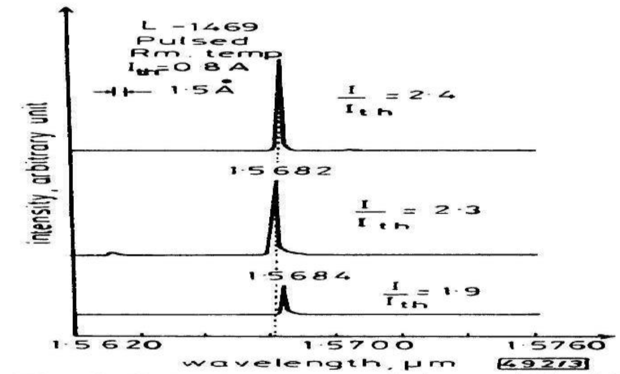


Fig. 3 *Output spectra of phase-shifted DFB laser*

Kazuhito Furuya

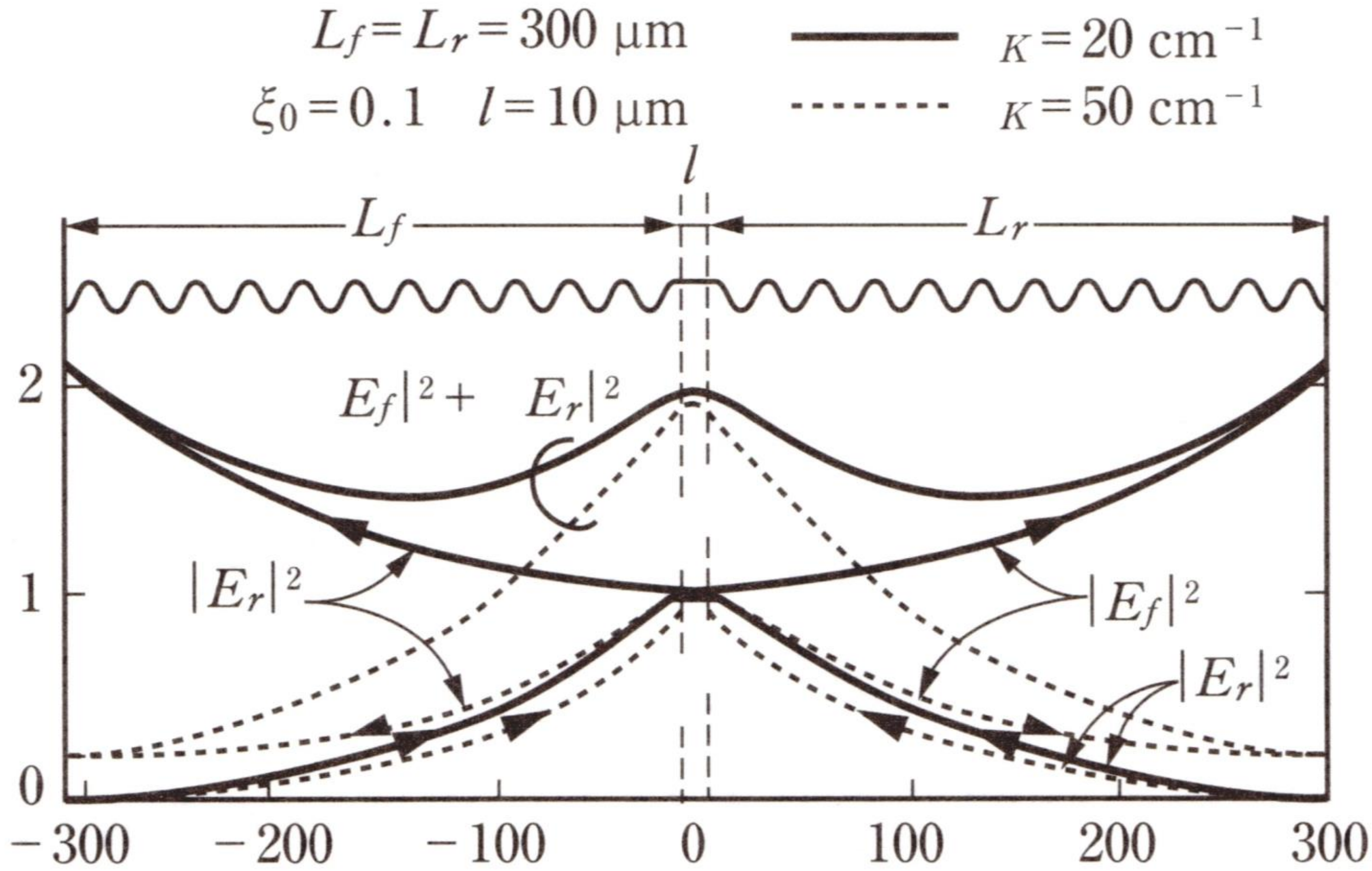
Sekartedjo [illegible] *Eda*

Fumio Koyama

Taui Tanbun-EK

K.Sekartedjo, N.Eda, K.Furuya, Y.Suematsu, F.Koyama and T.Tanbun-Ek, Electron. Lett., Vol.20, No.2, Jan. 1984.

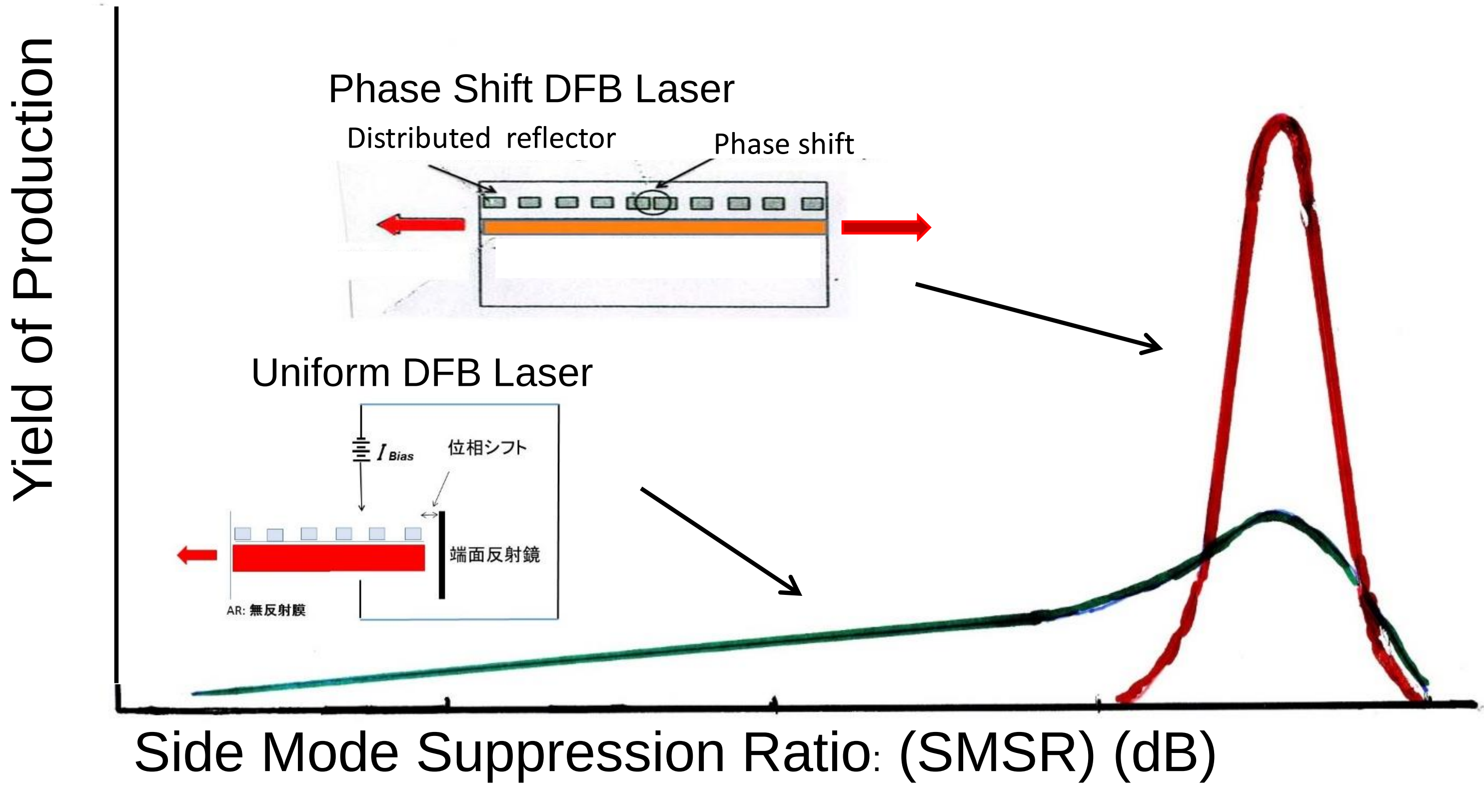
Field Distribution of Phase Shift Distributed Feedback Laser



Distance

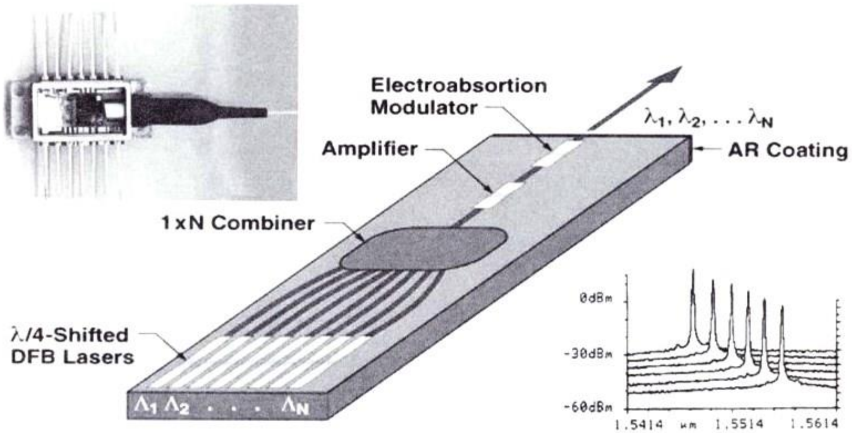
From "Optical Device"

Yield for Thermo-Tunable DSM Lasers



By courtesy of Mitsubishi Elect. Ltd. *2009*

Wavelength Tunable Laser Array

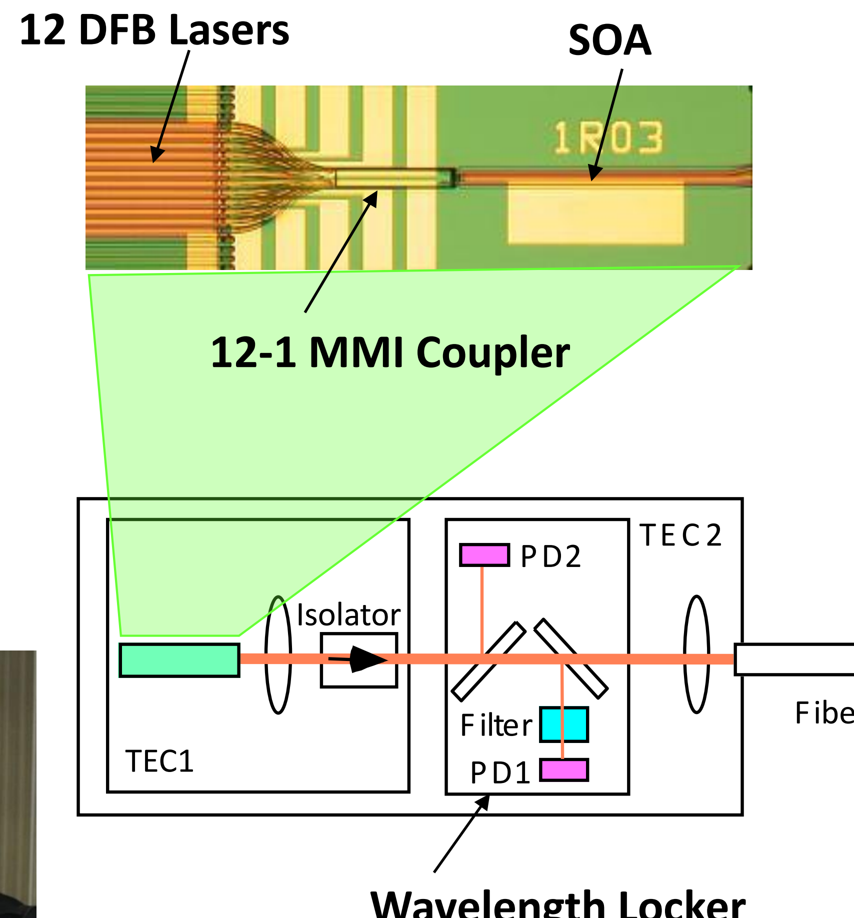


M.G. Young, U. Koren, H.I. Miller, M. Chien, T.L. Koch, et al, Electronics Lett. Vol. 31, p. 1835, 1995.

Thomas Koch (BTL)

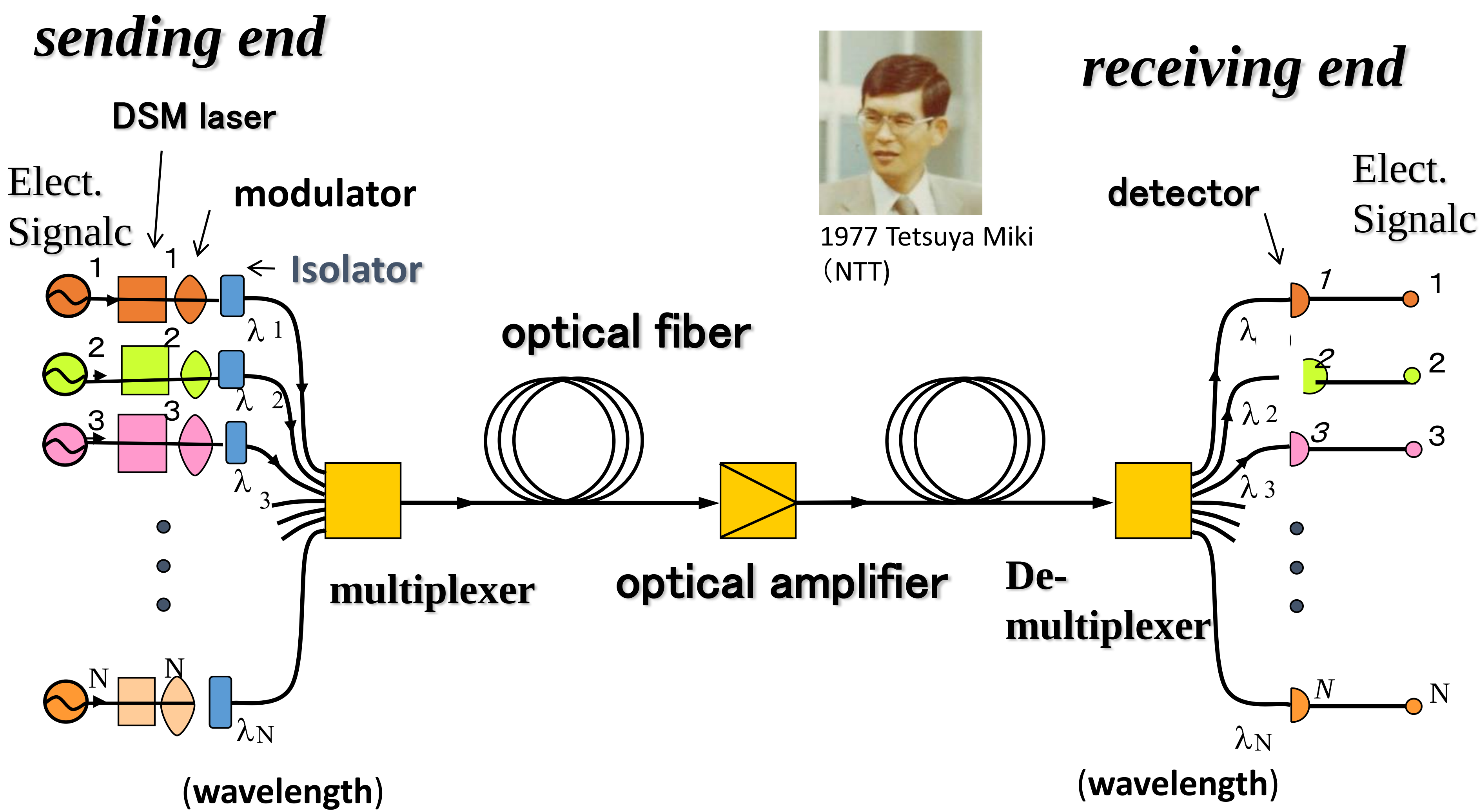
Hiromi Oohashi (NTT)

Laser Chip



H. Oohashi, Y. Shibata, H. Ishii, Y. Kawaguchi, Y. Kondo, Y. Yoshikuni, and Y. Tomori, IPRM, 2001.

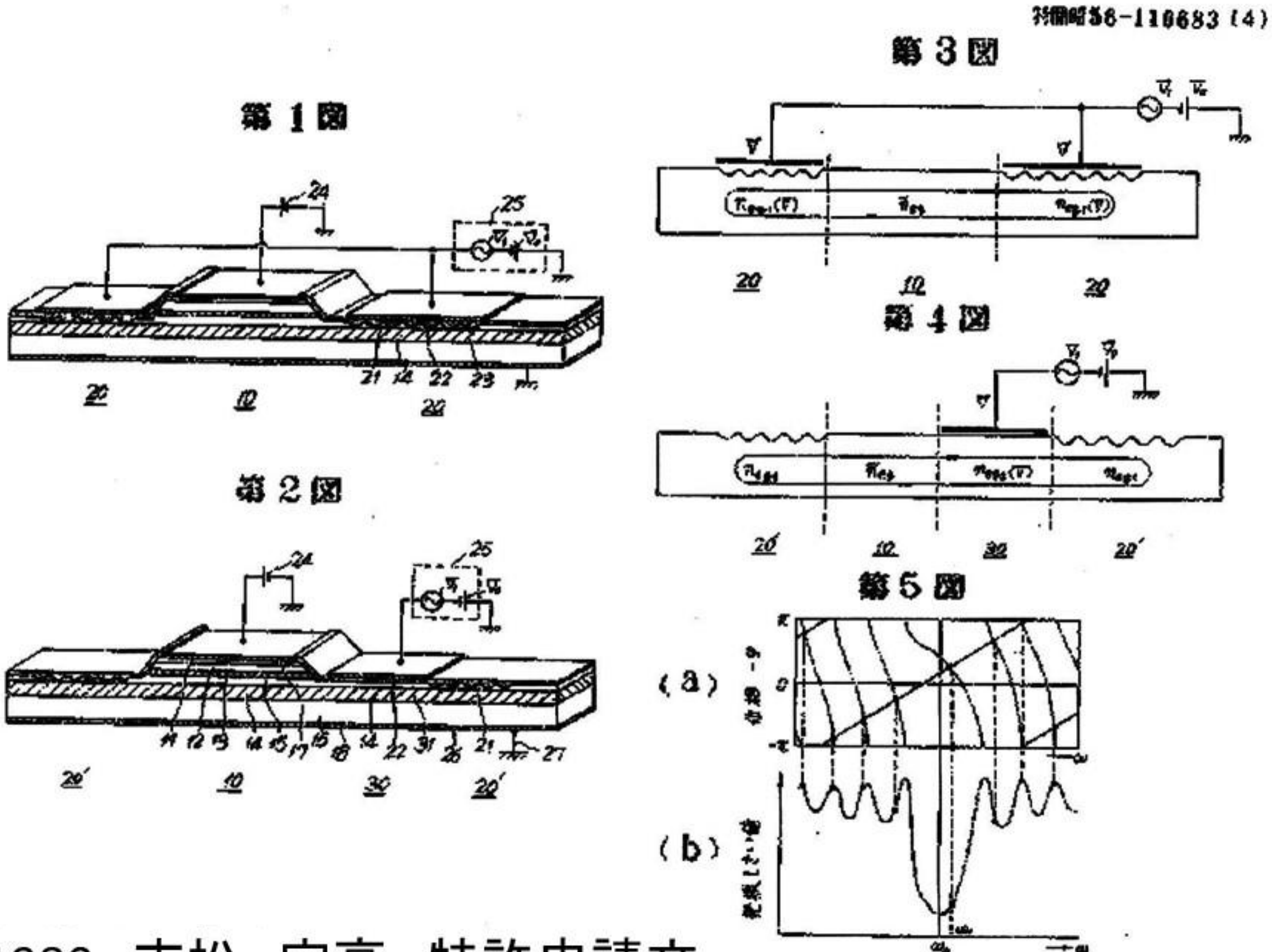
Wavelength-Division-Multiplexing(WDM) Optical Fiber Communication 1977



1977 Tetsuya Miki (NTT)

■ Proposal of Wavelength Tunable Laser *1980*

~ Electro-Tunable DSM Laser ~

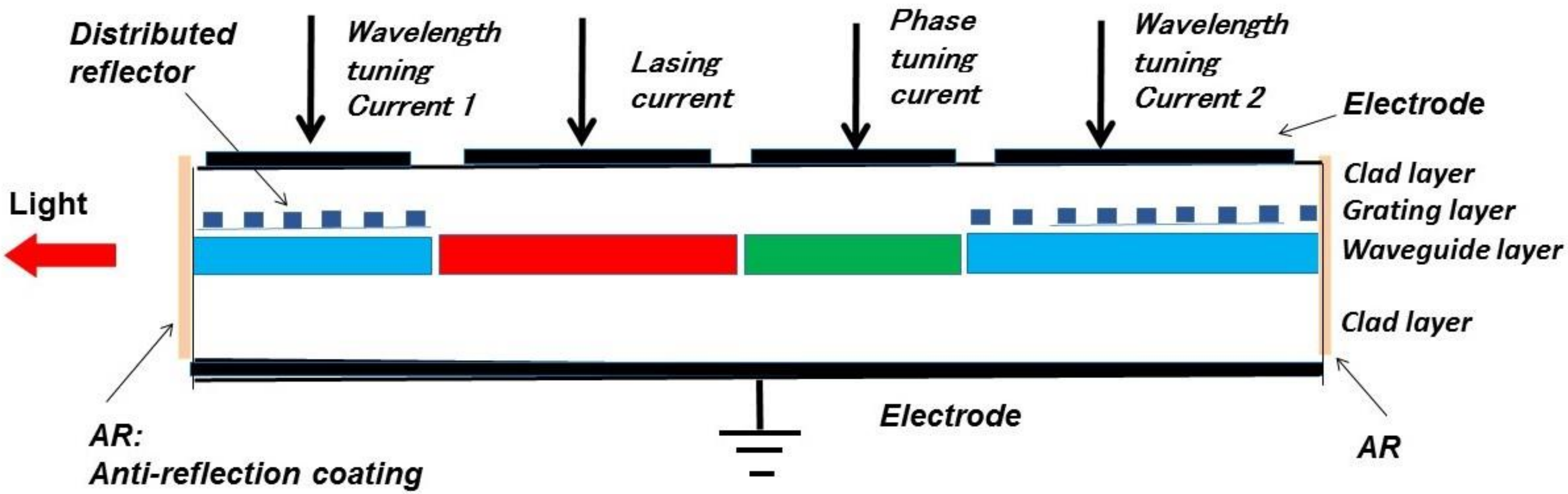


2015/6/25 1980 末松、宇高 特許申請文

Y. Suematsu and K. Utaka, Pattent Application, 1980

Katsuyuki Utaka

■ *Wavelength Tunable Laser*
~ Electro-Tunable DSM Laser ~



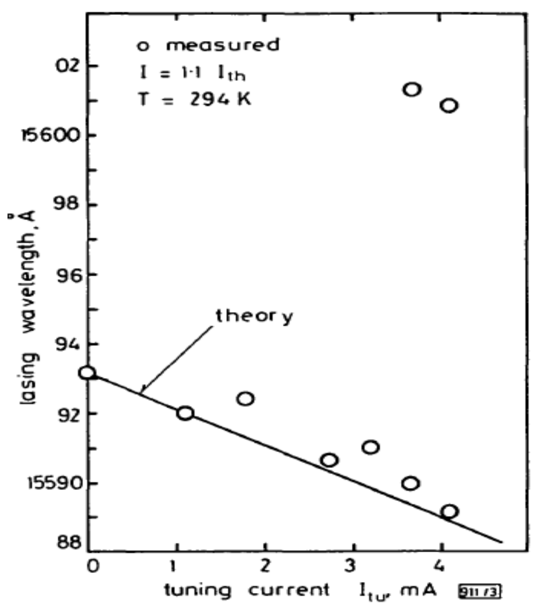
Katsuyuki Utaka

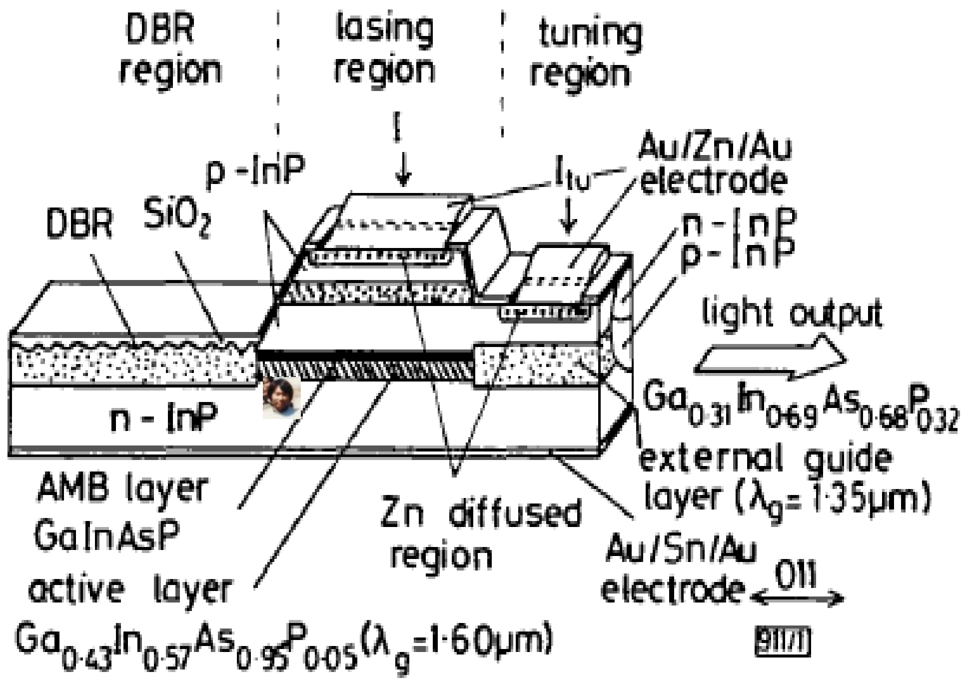
Yuuichi Tohmori

Proposal : Suematsu and Utaka, 1980

Theory : Tohmori, Jiang, and Suematsu, 1984

Demonstration of Wavelength Tunable Laser ~ Electro-Tunable DSM Laser ~ 1983





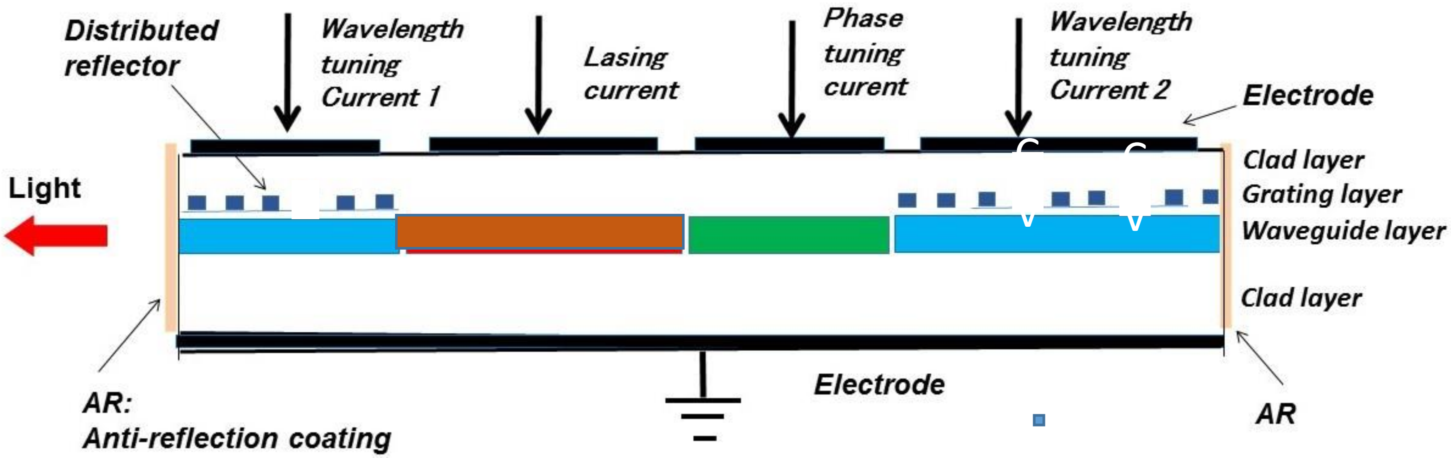
Yuuichi Tohmori

Hideaki Tsushima

Shigehisa Arai

Y. Tohmori, Y. Suematsu, H. Tsushima, and S. Arai, *Electron. Lett.*, vol. 19, no. 17, Aug. 1983.

Widely Tunable Laser with multi-interval gratings 1993



Yuuichi Tohmori (NTT)

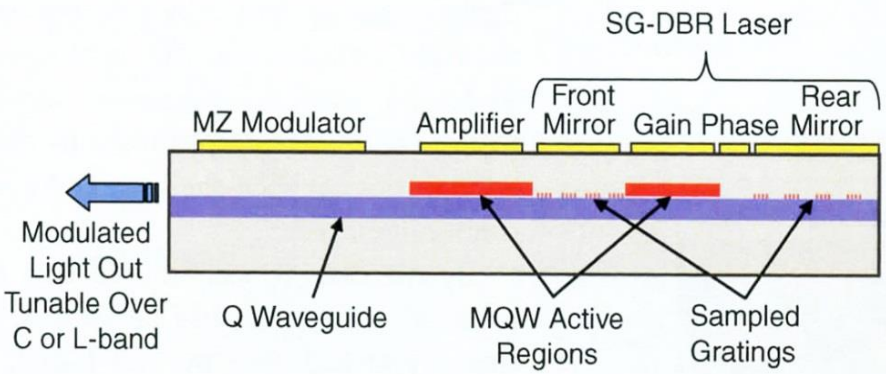
Yuhzou Yoshikuni (NTT)

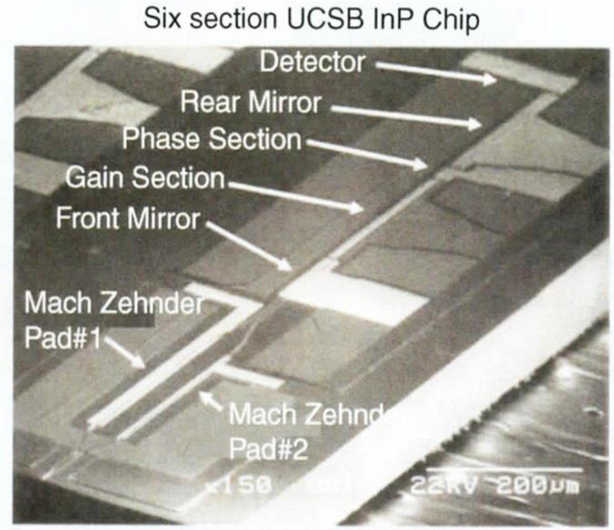
Larry Coldren (UC SB)

Y. Tohmori, Y. Yoshikuni, H. Ishii, etal, 1993

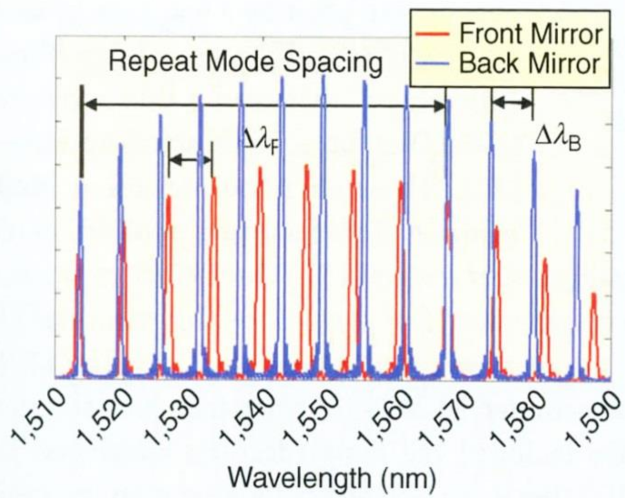
V. Jayaraman, Z.-M. Chuang, and L. A. Coldren, 1993

Widely Tunable SG-DBR-SOA-Modulator PIC 2011





Larry Coldren

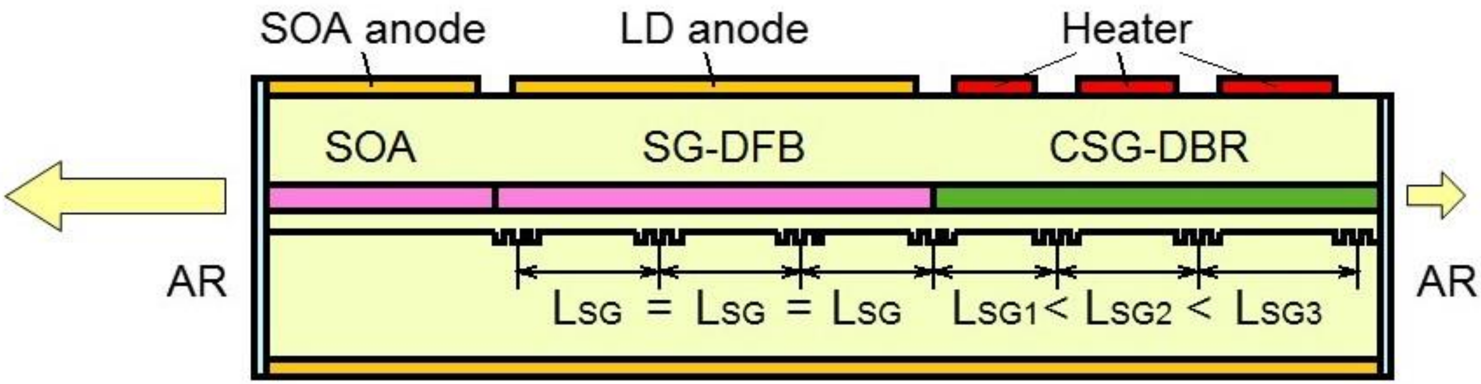


J. S. Barton, et al, "Tailorable Chirp using Integrated Mach-Zehnder Modulators with Tunable Sampled-Grating Distributed Bragg Reflector Lasers," ISLC,TuB3, Garmish, (Sept. 2002)

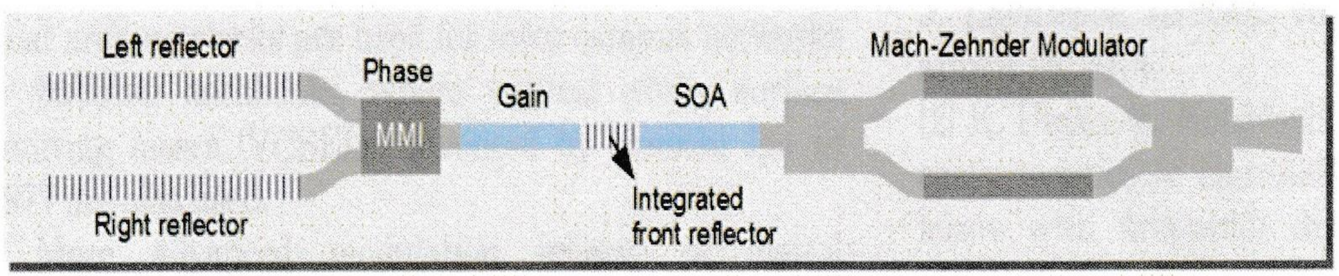
- Vernier tuning over 40+nm near 1550 nm
- SOA external to cavity provides power control
- Both EAM and MZ modulators integrated

L.A.Coldren
"Semiconductor Laser Advances,"
IEEE Photonic Res. Advances, Feb., 2011

Tunable Laser with Passive-Section Heater



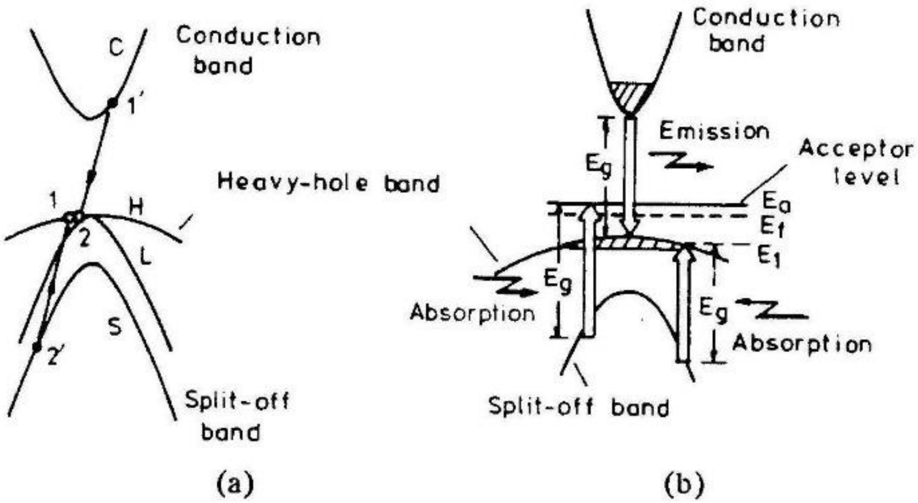
T.Kaneda, H. Mori, S. Onuki, etal, 1993



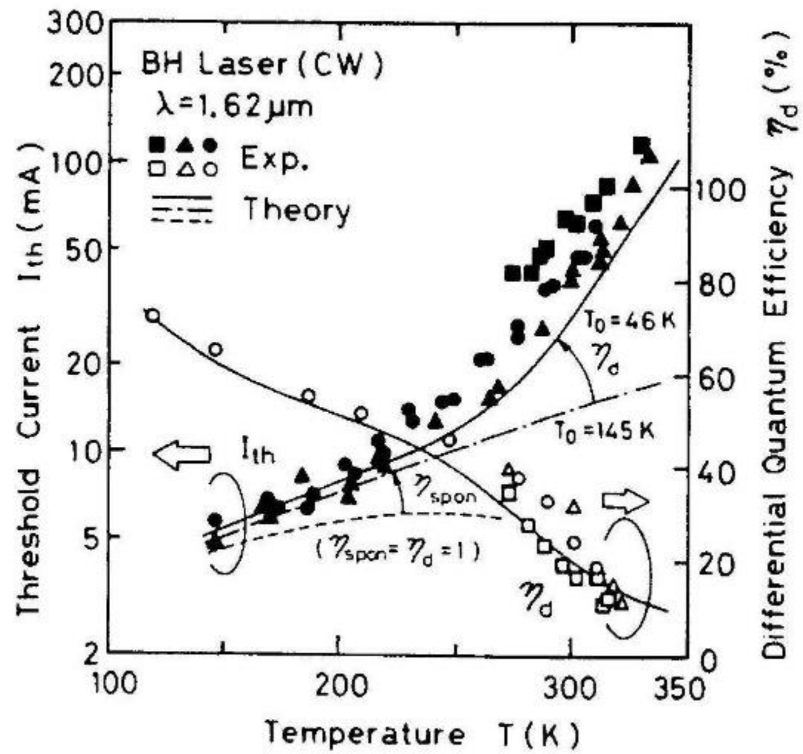
Schematic design of the monolithically integrated MGY-SOA-MZ transmitter

J. Q. Westroem.etal, 2004

Non-radiative Recombination of 1.5μm InGaAsP/InP Laser 1981



(a) (b)



Masahiro Asada

Alfred Adams

Kristian tubkjaer

M. Asada, A.R. Adams, K. Stubkjaer, Y. Suematsu, and S. Arai, 1981

Reduction of Threshold Current Density J_{th}

Nick Holonyak_Jr (Uni. Ill.)

Eli Yablonovich; Effective Mass 1986 (UC Berkley)

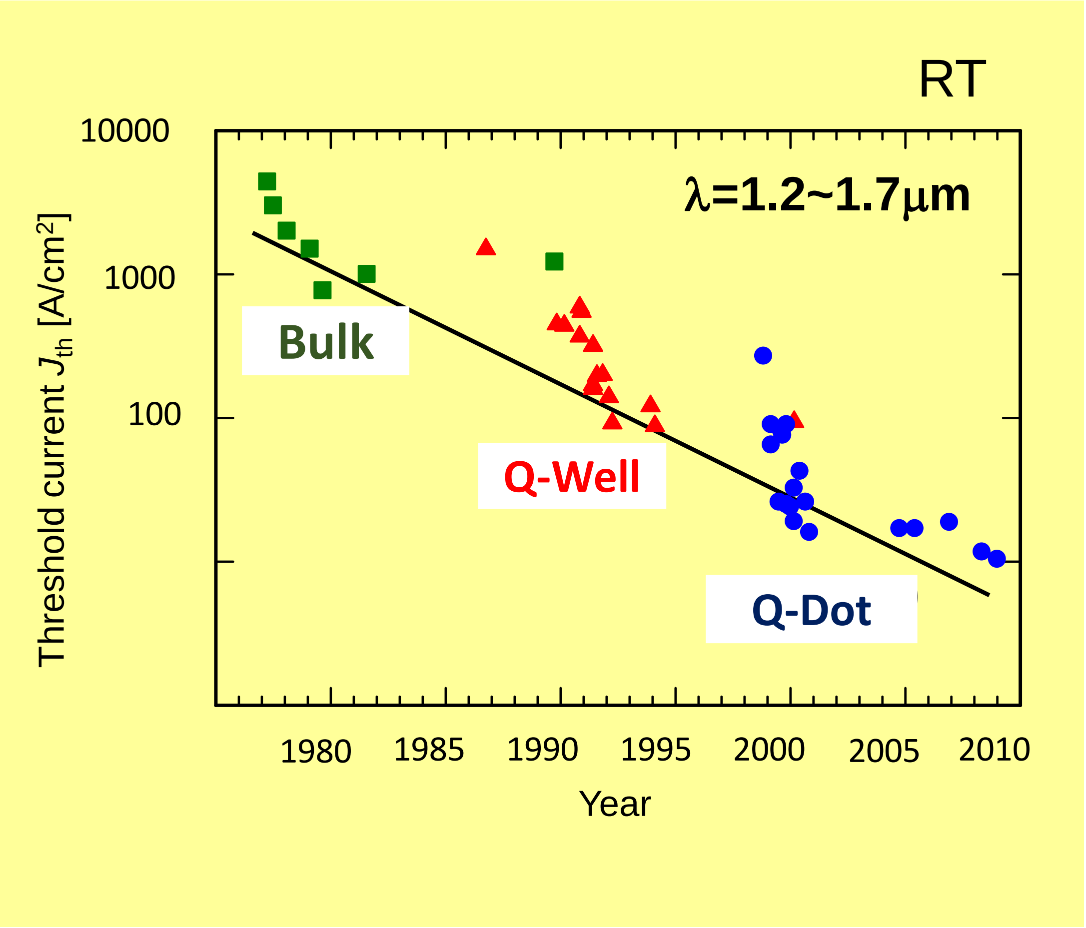
Alfred Adams BSE1984 (Surry)

10

Peter J. A. Thijs (Philips)
1.5μm MQW Strained LD 1991

Yasuhiko Arakawa 1982 QD (Tokyo Univ.)

Hiroyuki Sakaki QD 1982 (Tokyo Univ.)



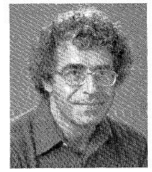
Early Semiconductor Laser Dynamics

G .
Lasher;
Band Tail
1964

Tesuhiko
Lkegami ;
Modulation
1967

Yoshio
Nishimura;
Hole Burn
1970

Magnus
Danielsen;
Rate. Eq.
1975



Robert
Olshansky;
Sub. Carrier
1975

Kourou
Kobayashi;
Enhance
1977

Kazuhiti
Furuya;
Spon.Emiss,
1978

Naoki
Chinone;
Mode
1978

Kenich
Iga;
Dynamics.
1978

Roy
Lang;
Inj.Lock.
1979

Sherman A
Haus.
Mode
1976

Shigeyuki
Akiba;
Mod.
1979

Chang-hi
Hong;
Distorsion
1979

Osamu
Hirota;
Reflection
1979

Minoru
Yamada;
Gain Sup.
1979

Kam Lau;
Distortion
1980

Fumio
Koyama;
Chir
1981

Katsumi
Kishino;
Chirp
1981

Kristian
Stukjar;
Non rad.
1981

Chuck
Henry
Spectrum
1982

Yasuhiko
Arakawa;
QD
1982

Tom
Koch;
Chirp
1984

John
Bower;
Chirp
1984cv

Alfred
Adams;
Band Struc.
1985

Masahiro
Asada;
QDL Gain
1985

Motoichi
Ohtsu;
Noise
1985

Amnon
Yariv;
QD
1985

Rod
Tacker
Mod.
1985

Eli
Yablonovich;
Valence B
1987

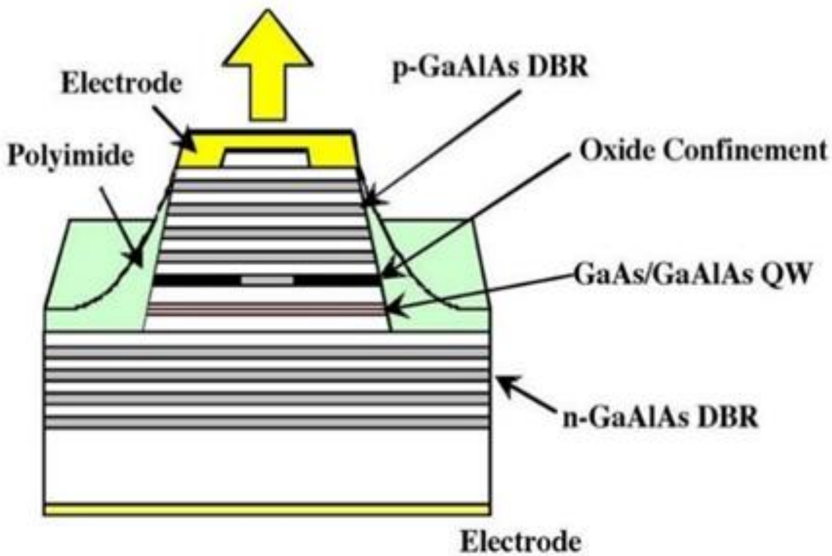
Markus
Amann,
Nnoise
1990

VCSEL ;Vertical Cavity Surface Emitting Laser

Structure of VCSEL

Small power operation

Two dimensional array

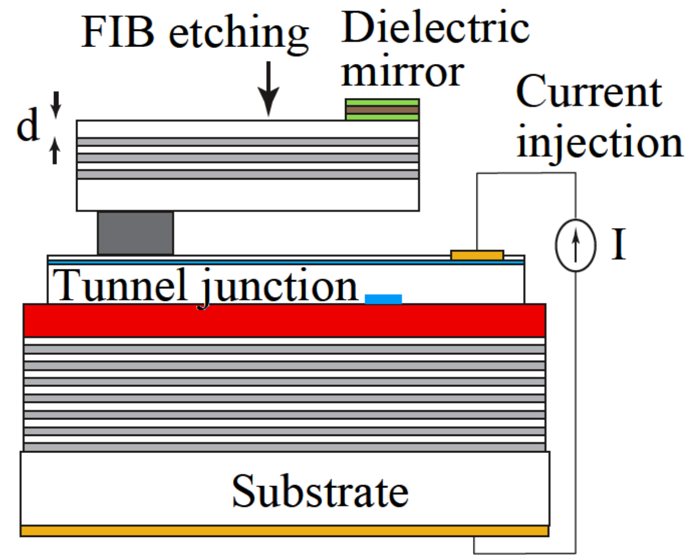


Kenichi Iga
1977

Proposal   K.Iga, 1977

RT-CW Operation,
F. Koyama & K. Iga,1988

Micro-machined VCSELs



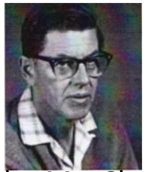
Humio Koyama
2006 Athermal

Connie Chang-Hasnain
2000 Tunable

Elements for Optical Fiber Communication

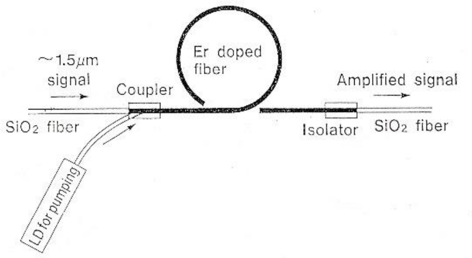
John B. MacChesney 1974 ***Ultra Low Loss Silica Fiber by MCVD***

Tatsuo Izawa 1977 ***Continuous Fiber Process by VAD***



John MacChesny
(BTL)

Tatsuo Izawa
(NTT)



Shojirou Kawakami、1974 Dispersion Shift Fiber

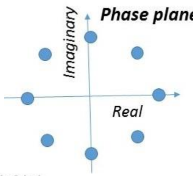
Shojiro Kawakam
(Tohoku Univ.)

David Payne 1986
Er+ Doped Optical Fiber Amplifier,
Masataka Nakazawa 1989
Laser Pumped Optical Fiber Amplifier

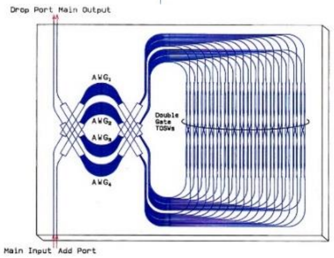
David Payne
(Southampton)

Masataku
Nakazawa
(Tohoku Univ.)

Phase modulation



Kazuo Kikuchi 2004 . Takanori Okoshi 1981
Digital Coherent Communication



PLC I990

Masao Kawachi
(NTT)

Kazuo Kikuchi
(Tokyo Univ.)

Takanori Okoshi
(Tokyo Univ.)

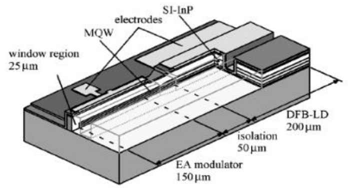


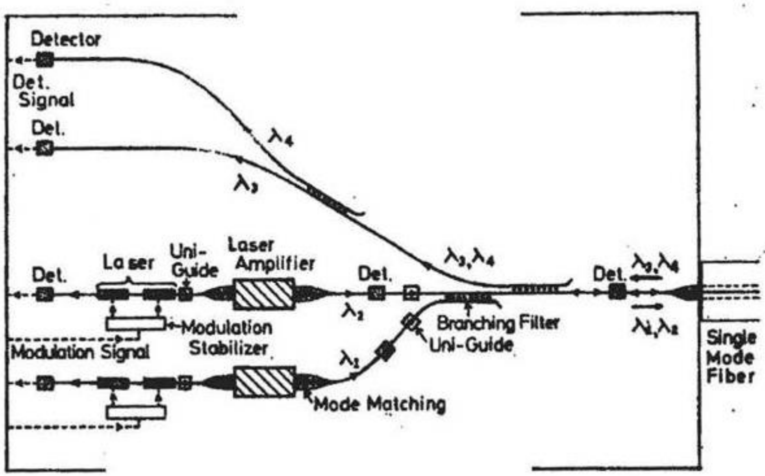
Fig. 1. Schematic of uncooled EML structure.

Komatsu I987
LiNbO3 Modulator

Federico Capasso I980
InGaAsP Photo Detector

Federico Capasso
(Harvard)

Photonic Integrated Circuits (PICs) toward Subsystem
～InP PICS and InP-Si Hybrid PICs～



Y. Suematsu, 1977

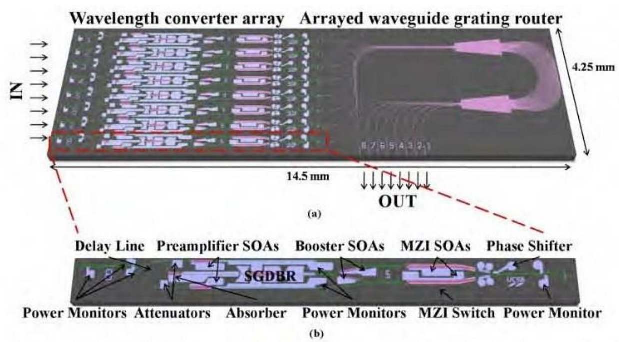
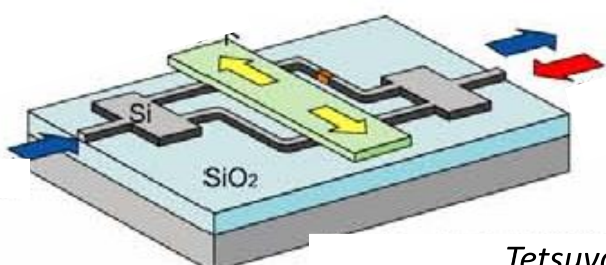


Fig. 2. (a) Schematic of overall MOTOR chip; (b) Expanded view of a single input wavelength converter showing several key devic

High Density In-PICs,
Coldren and Blumenthal, 2009

Daniel Blumental
(UC SB)

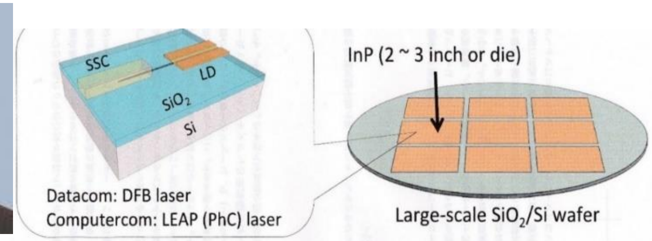


Tetsuya Mizumoto
(Toyo Tech.)

Planar Isolator
Tetsuya Mizumoto, 2006

John Bower;
(UCSB)

Shinji Matsuo
(NTT)）



InP-Si Hybri PICs

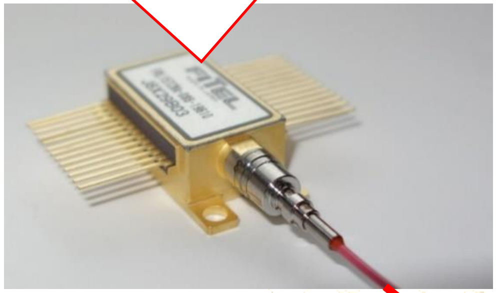
S.Matsuo, T. Fujii,
K. Hasebe, etal, , 2014

■**Laid down of Transe-Pacific Submarine Optical Cable TPC-4.**
First 1.5µm band system with Phase Shift DFB Laser, 1992. By courtesy of KDDI.

Yasuharu Suematsu

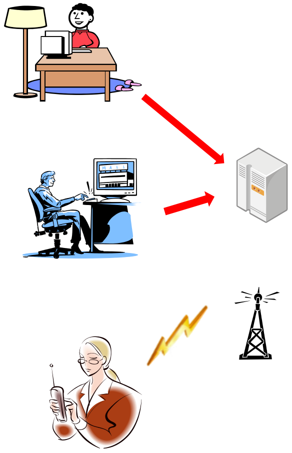
Optical Fiber Communication across the World

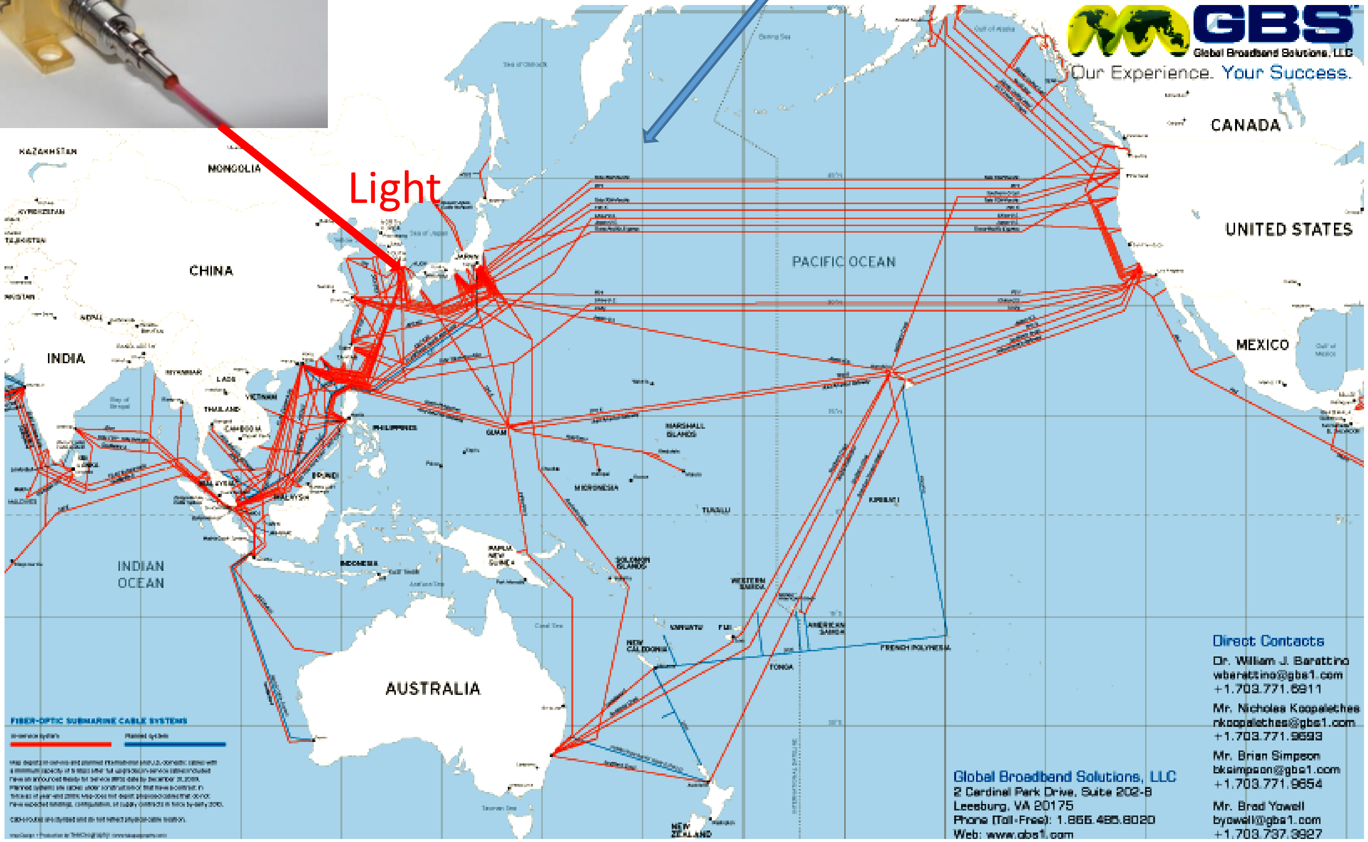
Dynamic Single Mode Laser



Trance Oceanic Submarine Cable
Overland Optical Cable
FTTH THz Mobile Connection

Light



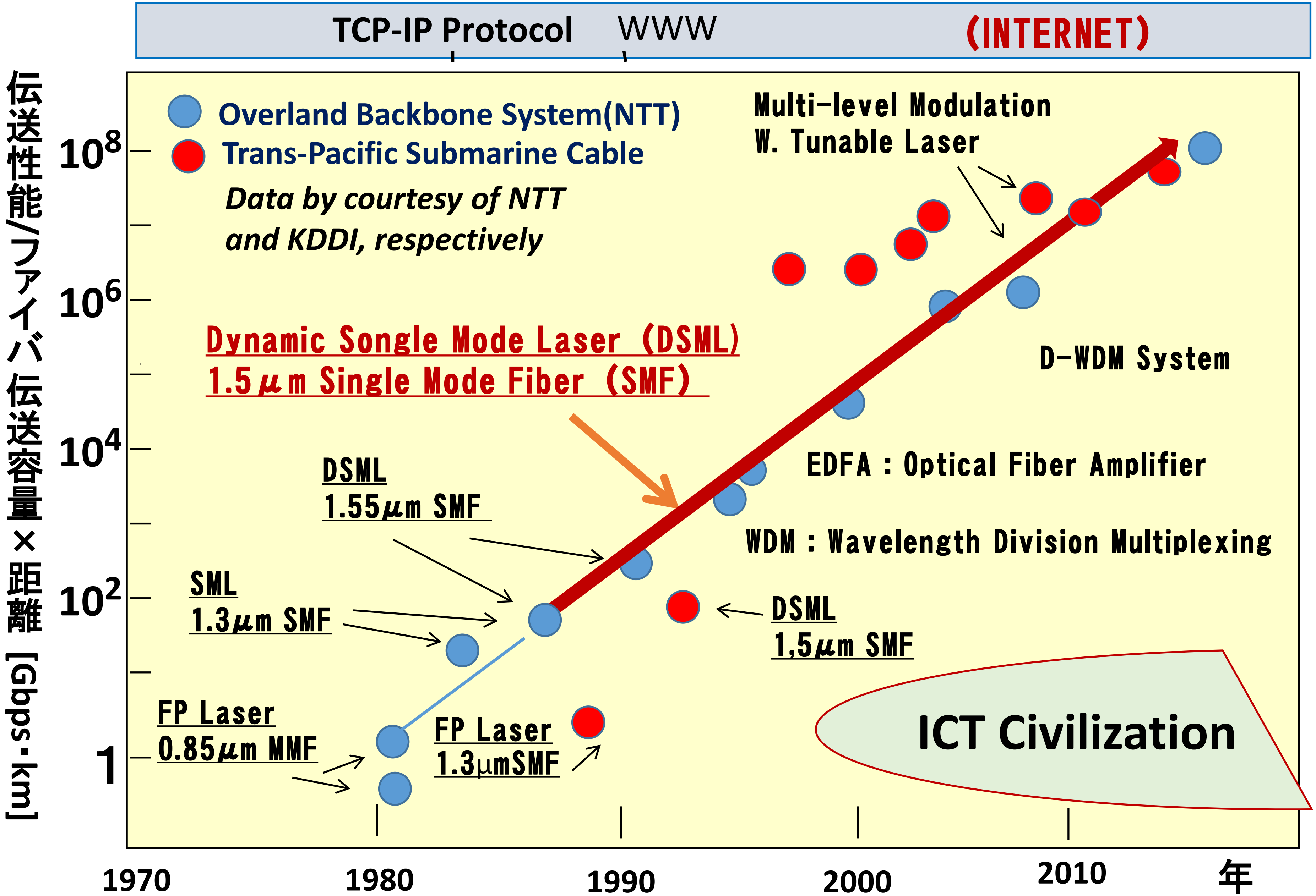


Basic Figure From Telegeography Co. Home Page

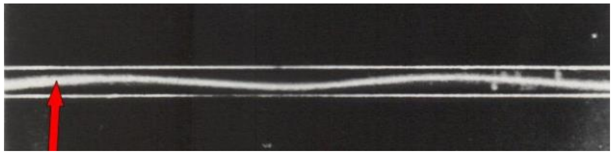
Optical Terminal at Home *well matured*

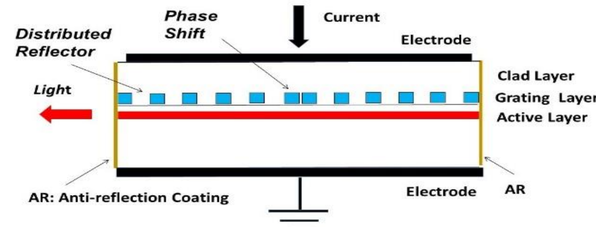
Cover removed (NTT) 2002−9

Performance of Commercial Optical Fiber Comm. Systems

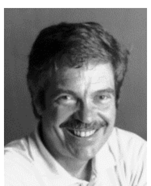


Research brought forth the ICT Society



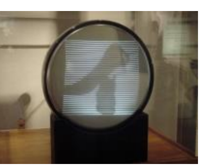


ICT Society



1970th Alan Key

Electronic display



1926 Kenjiro Takayanagi

1450 Johanes Gutenberg

Knowledge
Acquisition
High Capacity

2000

1960

INTERNET

High Capacity
Long Distance
Optical Fiber
Communication

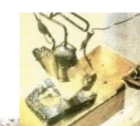
1973 Vinton Cerf

1973 Bob Kahn

Electrical communication

1944 amuel Mores

Immediate
Communication
Small Capacity



Finally it could be concluded
for
celebration
on
the Fifty Years Anniversary
of
Semiconductor Laser Conference
that
Semiconductor Laser Research
contributed greatly to bring forward
the Informatic Communication Civilization.

Thank you for your kind attention