

Diode Laser Active Region Evolution

Peter Zory – University of Florida

1962 to 1970

Diode Lasers: Diffused & Epitaxial GaAs **P-N** Junctions

Heterojunction Structures: Single **SH** & Double **DH**

1970 to 1980

Two Dimensional Waveguides **2D**

Corrugated Waveguides

Distributed Feedback **DFB** / Grating Coupling **GC**

1980 to 1990

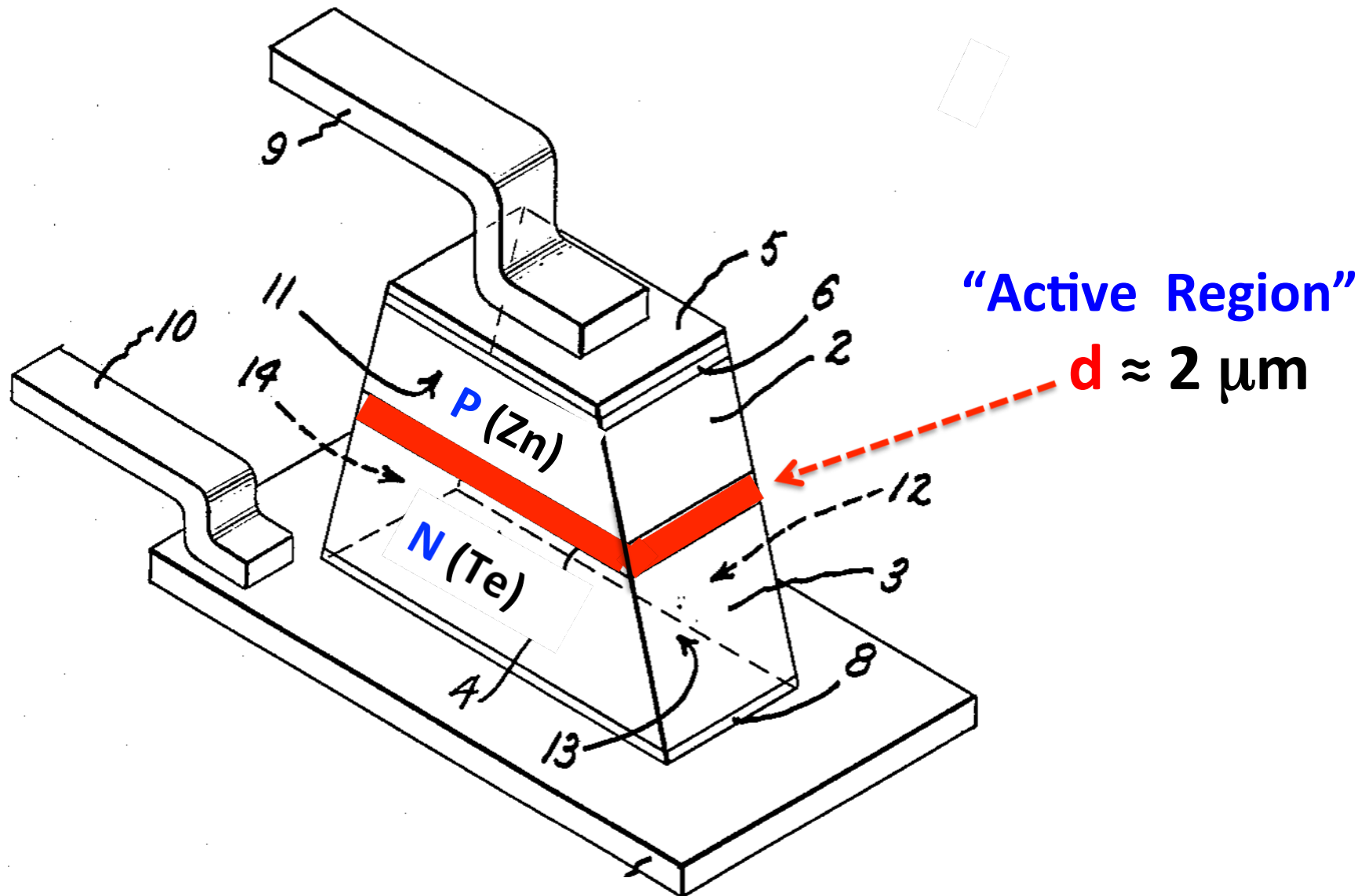
Compact Disc **CD** / Digital Video Disc **DVD**

8th Transatlantic Communications Cable **TAT-8**

Quantum Well **QW** / Photonic Integrated Circuit **PIC**

Vertical Cavity Surface Emitting Laser **VCSEL**

1st Diode Laser – Diffused P-N Junction 1962



US Patent 3,245,002 filed 24 October 1962 R. N. Hall General Electric

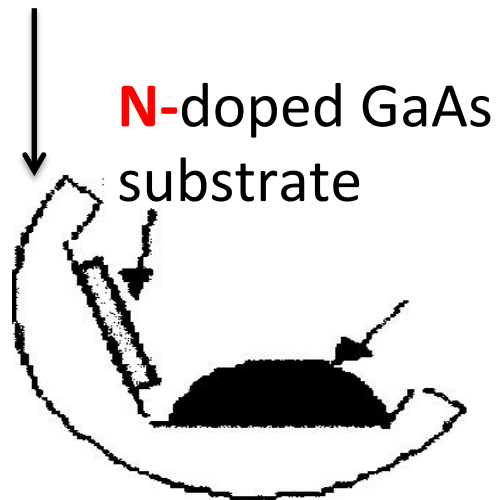
? Useful Power @ Room Temp 300⁰K

1963

Replace Diffused **P-N** Junctions
Liquid Phase Epitaxy **LPE**



Graphite Cylinder

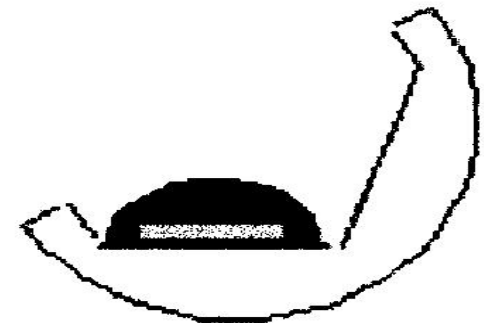


Equilibration

Liquid Gallium
GaAs chips
Zinc P-dopant



Tipping

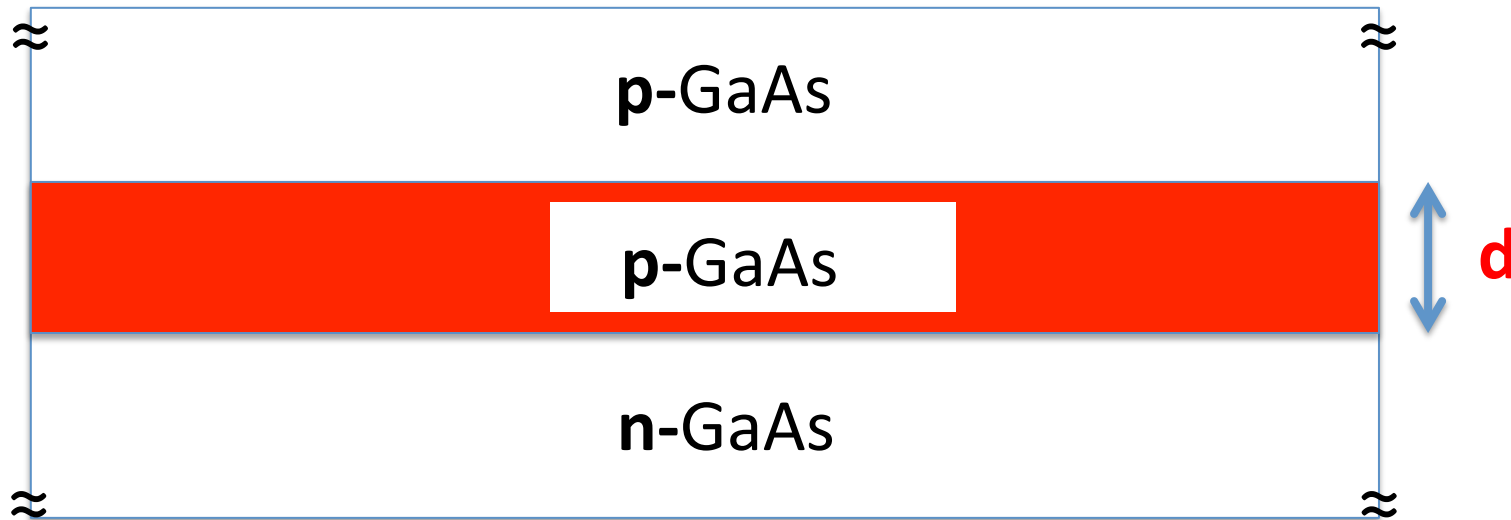


Growth

Epitaxial Laser Material

1966

Active Region Thickness $d \approx 2\mu\text{m}$



“Average” threshold current density

$$J_{th} \cong 30,000 \text{ Amps/cm}^2 @ 300^0\text{K}$$

Commercial Products

pulsed diode lasers & high power laser arrays

1966

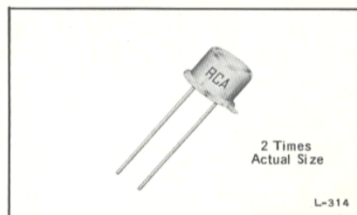
GALLIUM-ARSENIDE INJECTION-LASER DIODE FOR PULSE OPERATION

RCA
DEVELOPMENTAL TYPE
TA2628

RCA Dev. Type TA2628 is a p-n junction gallium-arsenide injection-laser diode which emits radiation, when forward biased, in the near infrared region of the spectrum. It is supplied in a modified TO-46 package with a low-absorbing glass window. It has alloyed contacts in both regions of its junction to provide good reliability and high thermal conductivity.

The TA2628 is designed especially for pulse operation with high modulation rates at room temperature. However, it may be operated in such service within the temperature range of -196°C to $+50^{\circ}\text{C}$. It will have high power output and high power efficiency. The TA2628 is well suited for communications, ranging and guidance systems, instrumentation, control equipment, and other applications utilizing nanosecond pulse widths at high repetition rates.

Radiation from the TA2628 is emitted in a direction perpendicular to the plane of the header. Beam spread at room temperature is 15° in a plane parallel to and 5° in a plane perpendicular to the junction. Although beam spread increases slightly with increasing operating temperature, it may be reduced to a fraction of a degree at all temperatures by means of a suitable optical lens.



- Wavelength of Peak Emission
at 27°C — $9050 \pm 50 \text{ \AA}$
- High Peak Power Output —
2 Watts Typical at Peak
Pulse Current of
30 Amperes
- High Power Efficiency —
Typically 0.5% at 27°C and
Peak Pulse Current of 30 Amperes

DATA

General:

Wavelength of Peak Emission at $+27^{\circ}\text{C}$ (300°K):

Peak	9050 ± 50	angstroms
Line width at half-power points (Energy Spectrum)	5 to 10	angstroms
Emitting Area	1×10^{-5}	cm^2

For further information or application assistance on this device, contact your RCA Field Representative or write RCA Solid State Optical Product Marketing, RCA, Somerville, N. J.

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TA2628 12-66

RCA
GaAs Pulsed Laser

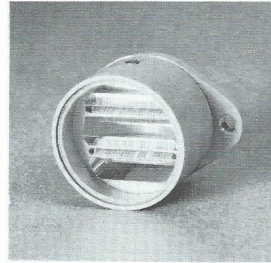
300°K
2 W out @ 30 A

pulse width < 200 ns

wavelength 905 nm

**800 WATT
GALLIUM ARSENIDE LASER ARRAY**

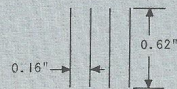
- PULSED OPERATION AT ROOM TEMPERATURE



ACTUAL SIZE

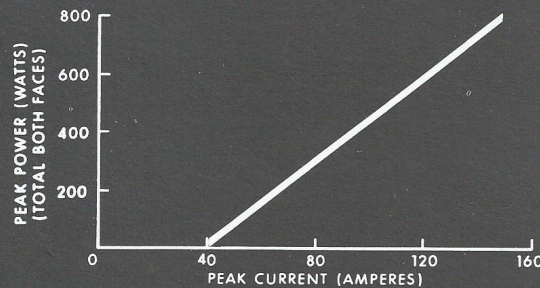
TYPICAL OPERATING CHARACTERISTICS (27°C)

POWER OUTPUT	PEAK	800 WATTS
PULSE WIDTH	1/2 POWER	80 NANOSECONDS
SPECTRUM	PEAK	9160 Å
	1/2 POWER	9110 Å - 9190 Å
BEAM WIDTH		0.1 STERADIAN
REPETITION RATE		≤1000 PPS
FORWARD IMPEDANCE		2 SEPARATE INPUTS, EACH APPROX. 2 OHM
NEAR FIELD PATTERN		



REQUIRED INPUT CURRENT PULSE*
-PEAK 150 AMPS
-WIDTH 100 NANOSECONDS
-RISE TIME 20 NANOSECONDS

*e.g. MODULATOR TYPE EO 150-04



SPERRY
ELECTRO-OPTICS GROUP
SPERRY GYROSCOPE DIVISION
GREAT NECK, N.Y. 11020
PHONE 516-574-2292

**Sperry Rand
GaAs Laser Array**

300°K

800 W out @ 150 A

80 ns pulse width

Wavelength 915nm

ISLC-1

Las Vegas, Nevada, USA

1967

Sands Hotel



Celebrities



Howard Hughes



Sammy Davis Jr.

- * Epitaxial GaAs **P-N** Junction lasers
turn-on delay and modulation speeds
- * Stripe geometry lasers
beam instabilities with current change
- * Homojunction laser theory
peak optical gain **g** vs current density **J**
- * **? Is Continuous Wave CW operation possible @ 300⁰K ?**

Paper V-1 IBM Research

“Stimulated emission from $\text{Ga}_{1-x}\text{Al}_x\text{As}$ diodes”

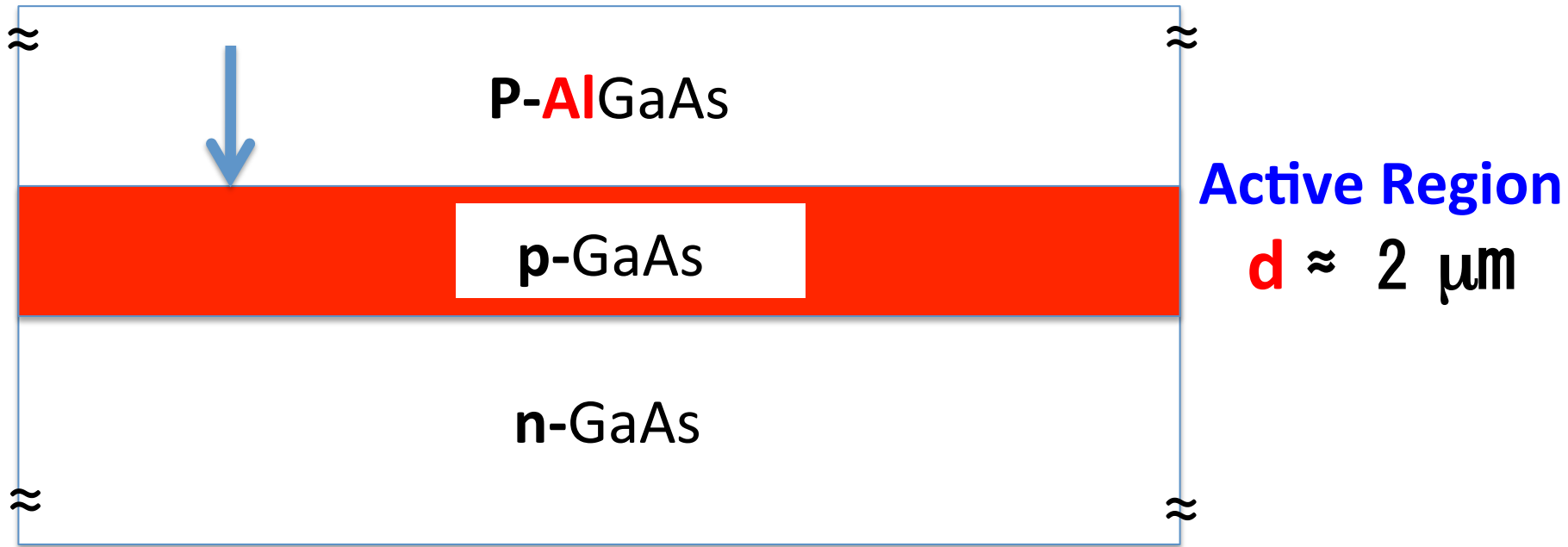
$\lambda = 750 \text{ nm}$ at 77^0K

J. Quantum Electronics v4 p68 January 1968

Single Heterojunction SH Structure

1968

Material grown by Single Layer LPE

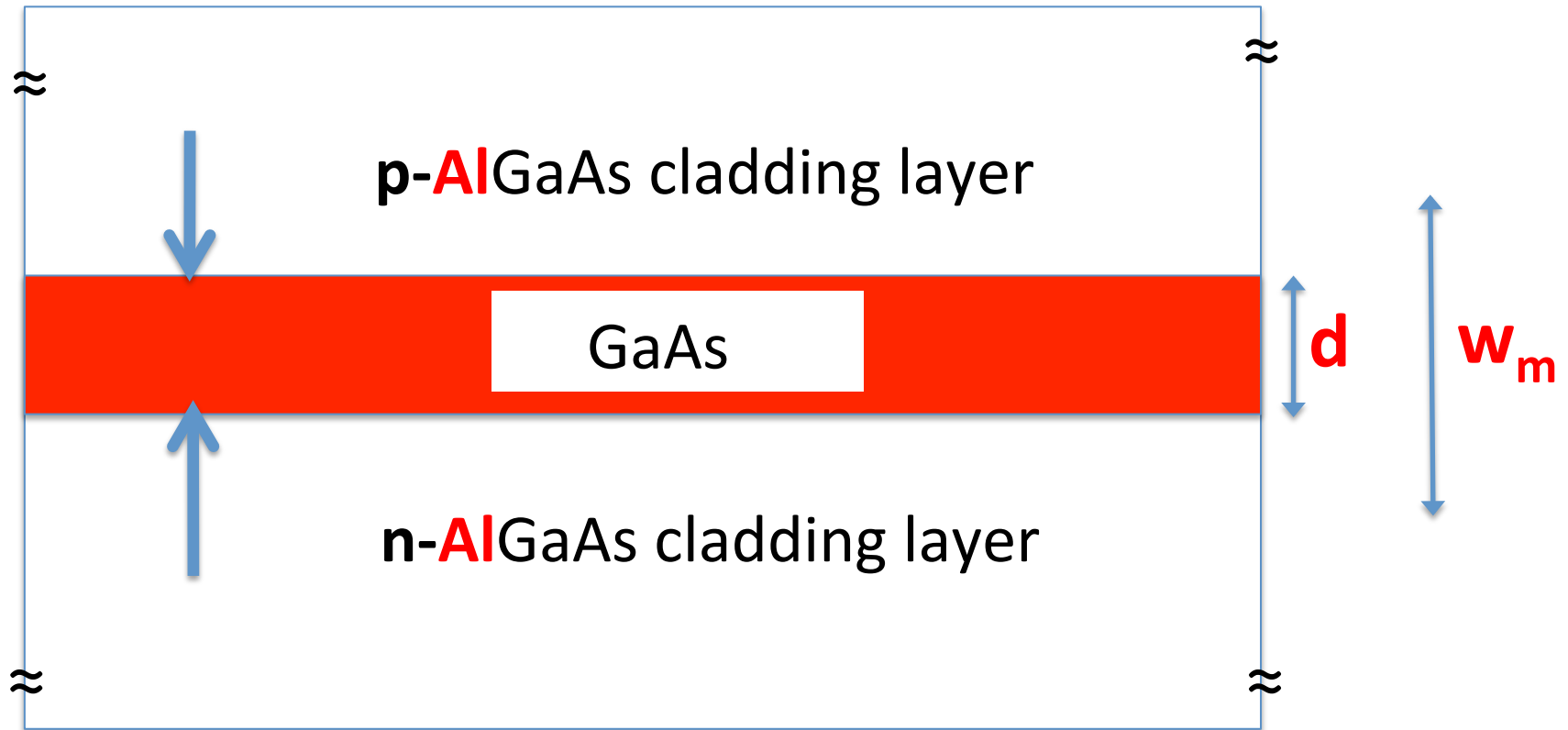


Typical threshold current density

$$J_{\text{th}} \approx 8,000 \text{ Amps/cm}^2 @ 300^\circ\text{K}$$

? Double Heterojunction DH Possible ? 1968

? How Does One Make a Multilayer Structure ?



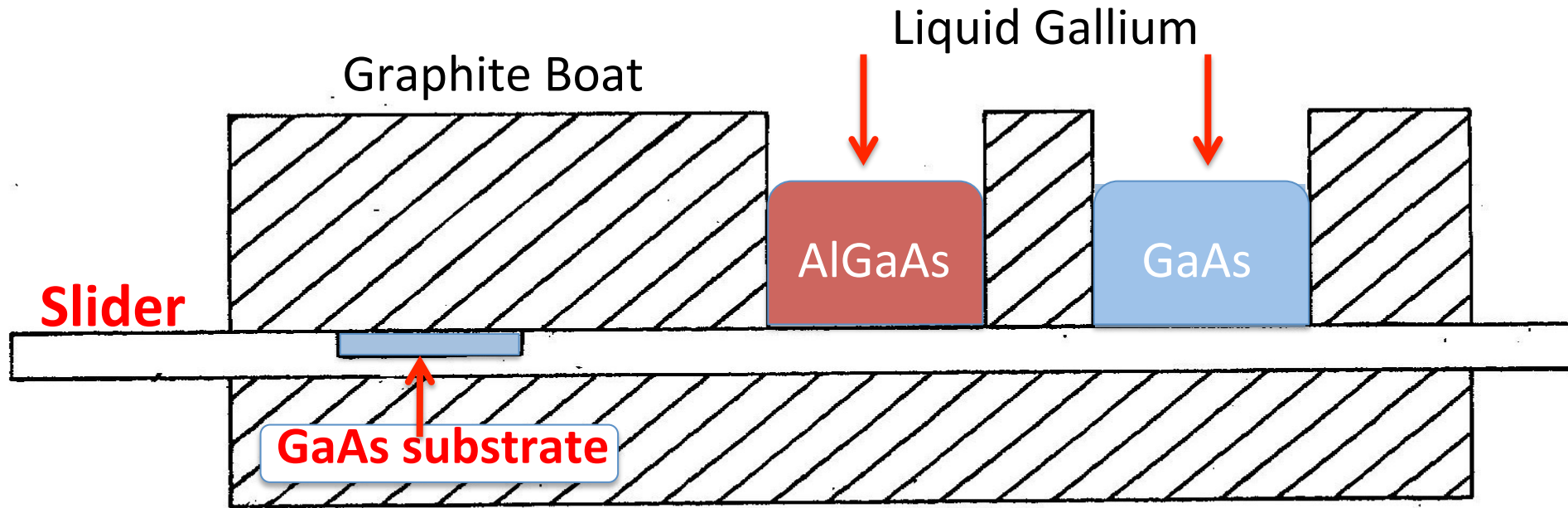
Carriers confined in photon amplifying layer - thickness d

Photons confined in **1D** waveguide mode - width w_m

Active Region: d enclosed in w_m

1969

Substrate Slider Design for Multilayer LPE Growth



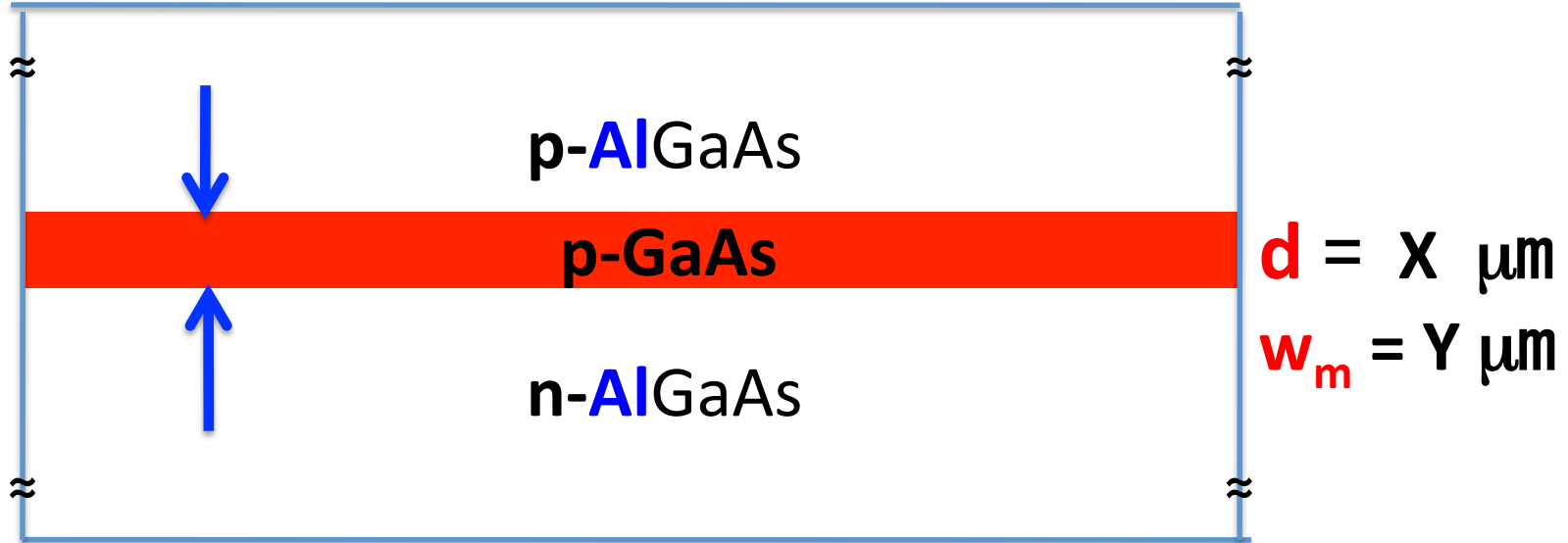
US patent application filed on above design in February 1969 RCA

ISLC-2 Mexico City Discussion topics 1969

* Single Heterojunction **SH** lasers: turn-on delay and reliability issues

* Close Confined Lasers - (**DH** acronym not yet used)

Active Region: gain layer of width **d** enclosed in **1D** mode width **w_m**
problem: “rabbit-ear” modes perpendicular to junction plane



DH structure used in first 300°K **CW** diode laser

Early Summer 1970

Ioffe Institute, Russia

Bell Laboratories, USA

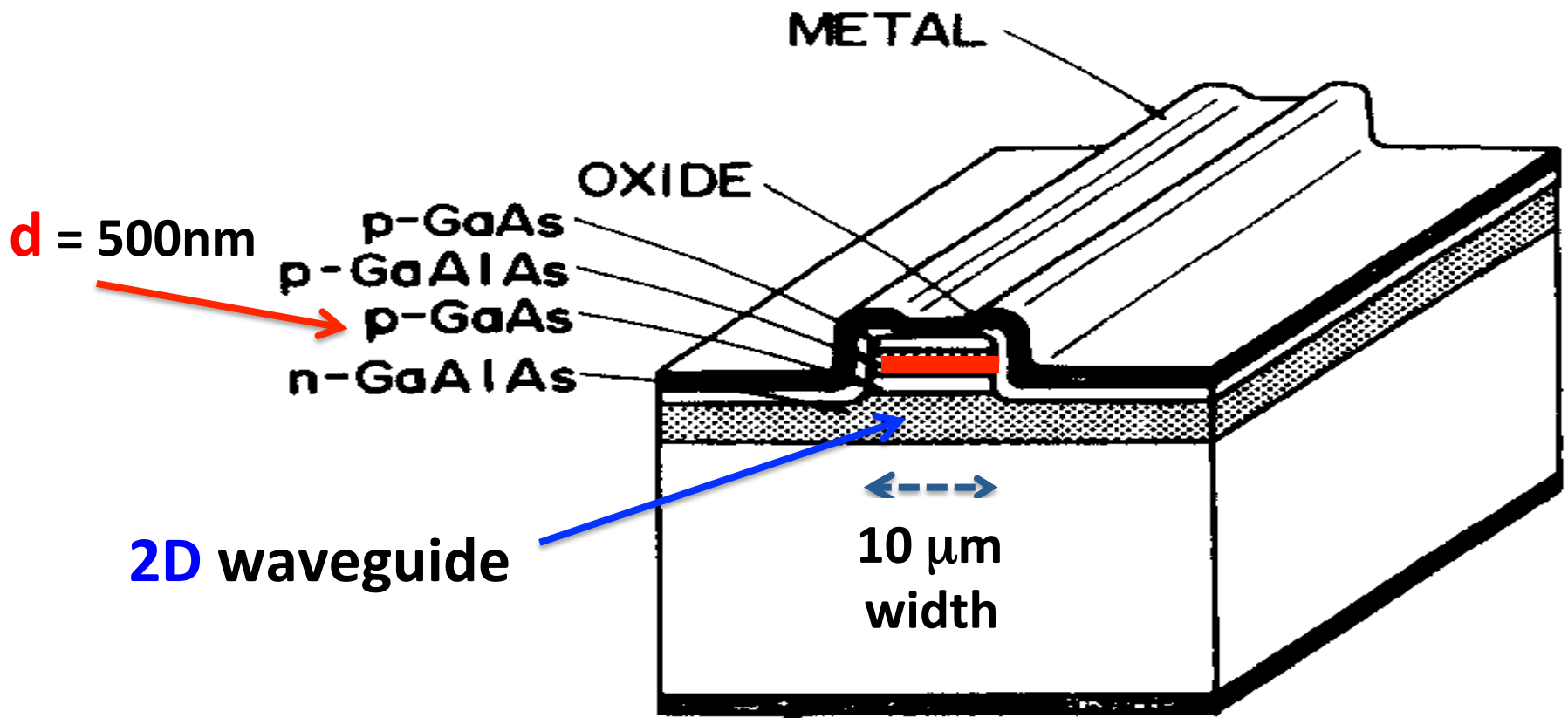
* **Lifetime** - **DH** lasers operating **CW** at 300⁰K
self pulsing (≈ 500 Mb/sec) - bad for com laser
1D waveguide with **3** layers

1D waveguide with **4** layers
Large optical cavity **LOC** structure

1D waveguide with **5** layers
Local Gain Region **LGR** structure
or Separate Confinement Heterostructure **SCH**

2D waveguide: Carriers & Photons Confined in **2D**
Mesa-Stripe-Geometry **DH** Laser

ISLC-3 Mesa-Stripe-Geometry DH Laser 1972



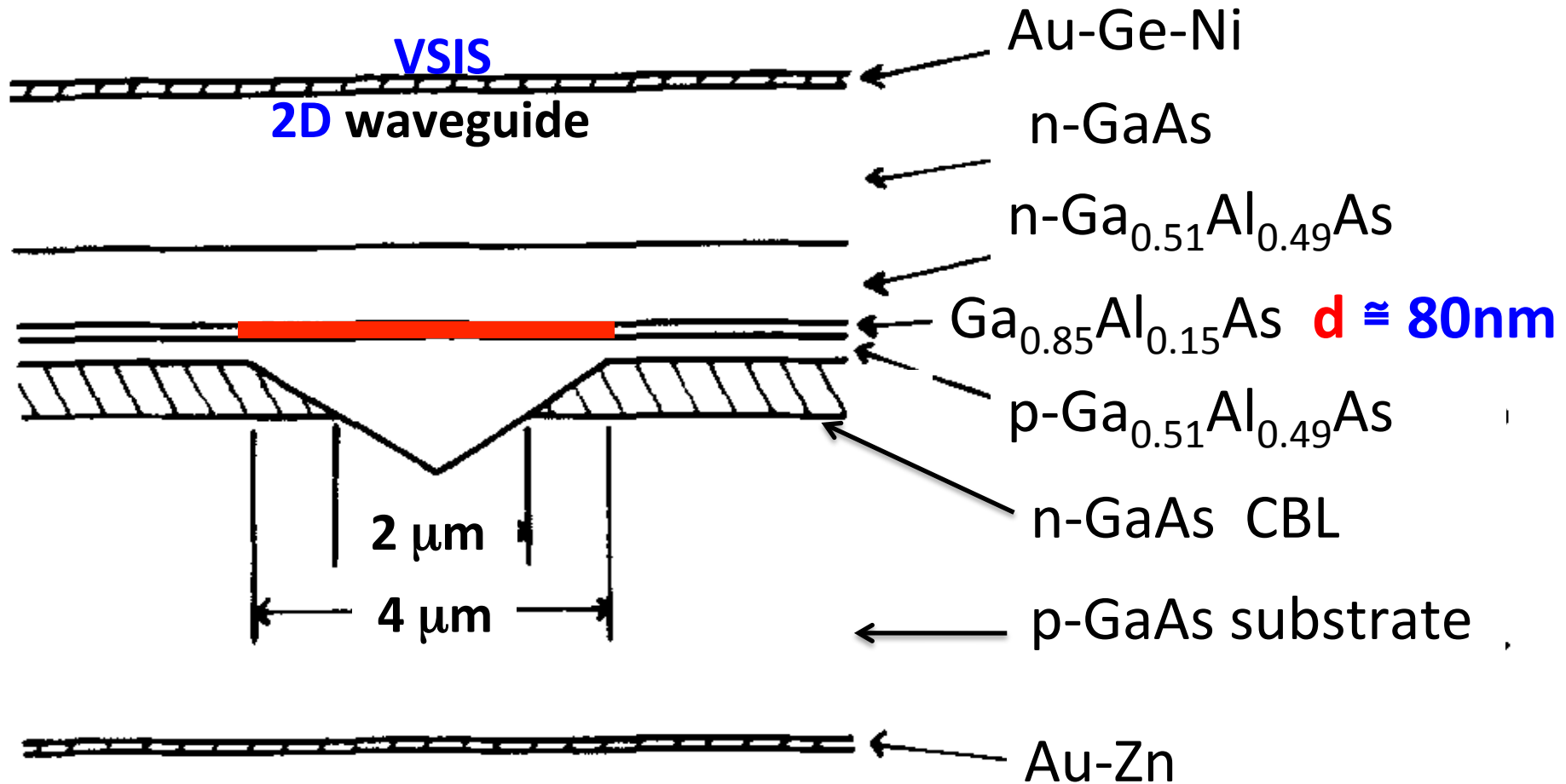
ISLC-3 Boston paper PD2 Hitachi Ltd

"Optical Characteristics of Mesa-Stripe-Geometry DH Lasers"

Applied Physics Letters v20 p344 May 1972

ISLC-8 1st mass-produced laser-CD players 1982

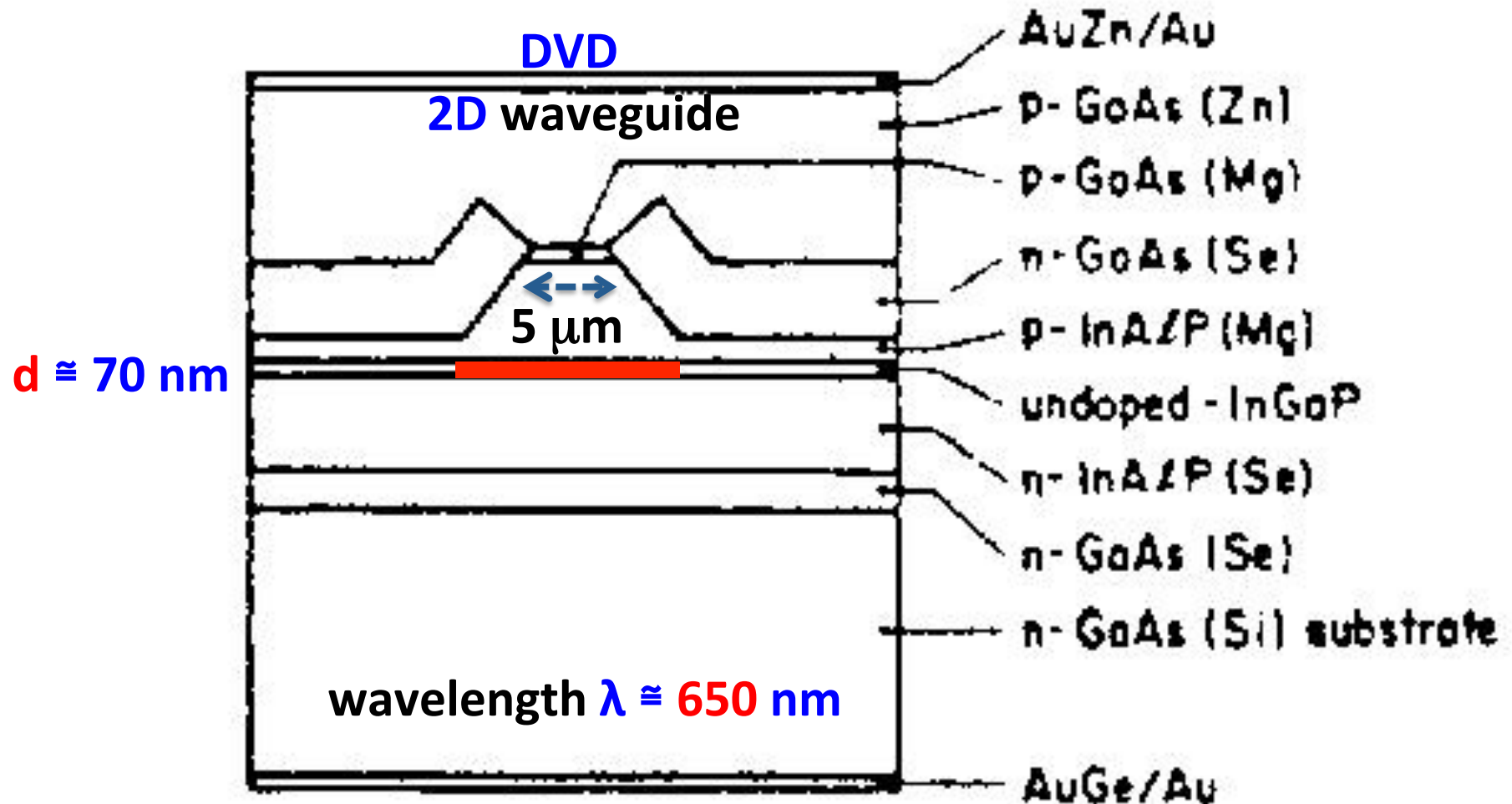
CD wavelength standard $\lambda = 780 \text{ nm}$



ISLC-8 Ottawa paper 12 Sharp Corp.

Applied Physics Letters v40 p372 1982

ISLC-10 Red DH laser operating CW 300K 1986



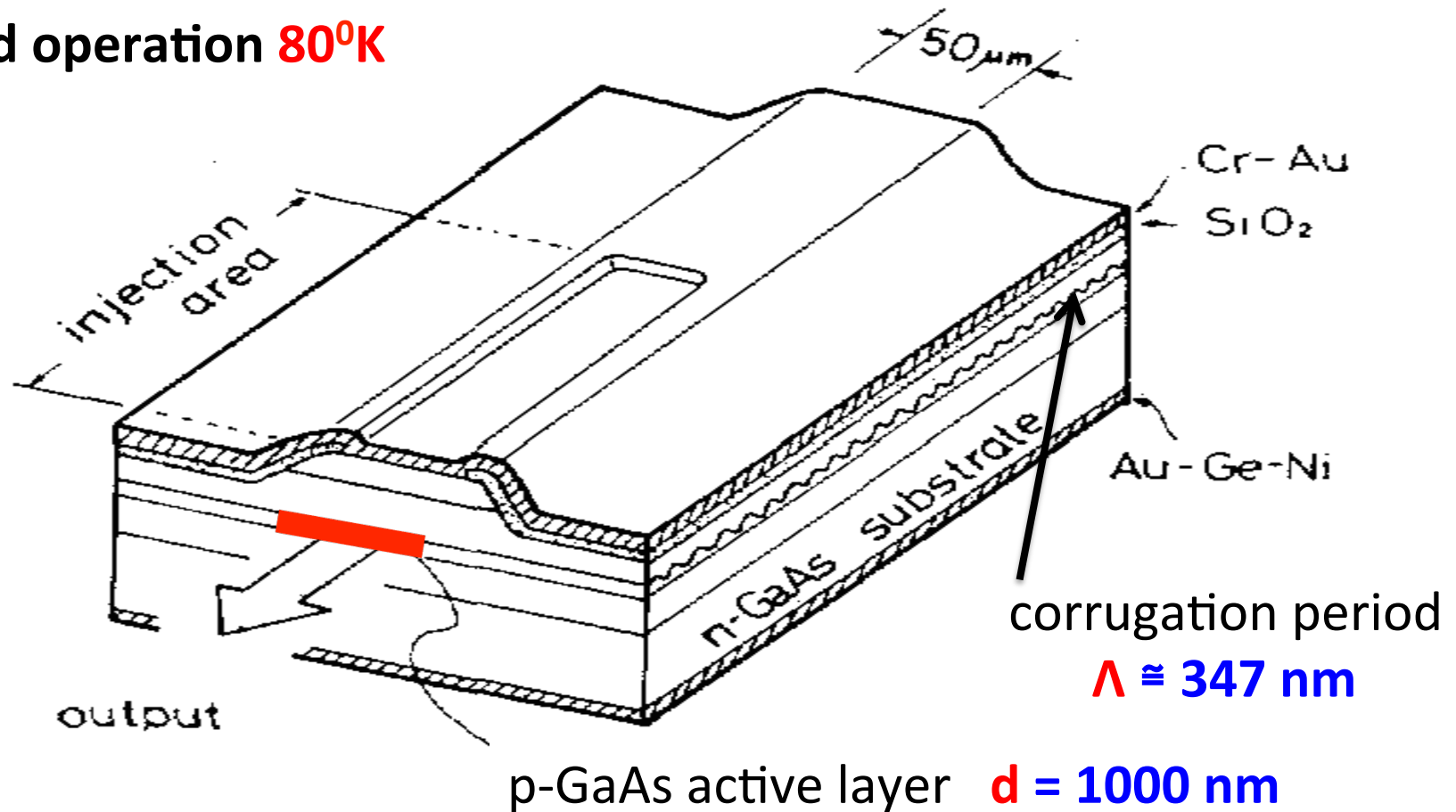
ISCL-10 Kanazawa paper A-1 Toshiba Corp.

“Low Threshold Current InGaP/InAlP Transverse Mode Stabilized Laser”
Applied Physics Letters v 48 p207 1986

- * **DH** laser reliability: dark-line-defect **DLD** / transient effects
- * **DH** & **SCH** laser performance: optimal **active layer** thickness **d**
- * Cryogenic Lead-Salt lasers operating in the mid-infrared
- * New **2D** waveguide structure
buried heterojunction **BH**
- * New **1D** active region
corrugated waveguide
narrow spectral band operation
single longitudinal mode **SLM**
Distributed Feedback **DFB** Laser

ISLC-4 DH laser - corrugated active region 1974

Distributed Feedback DFB Laser
pulsed operation 80°K



ISLC-4 Atlanta paper B5 Hitachi Ltd / Cal Tech

“GaAs-GaAlAs DH Injection Lasers with DFB”

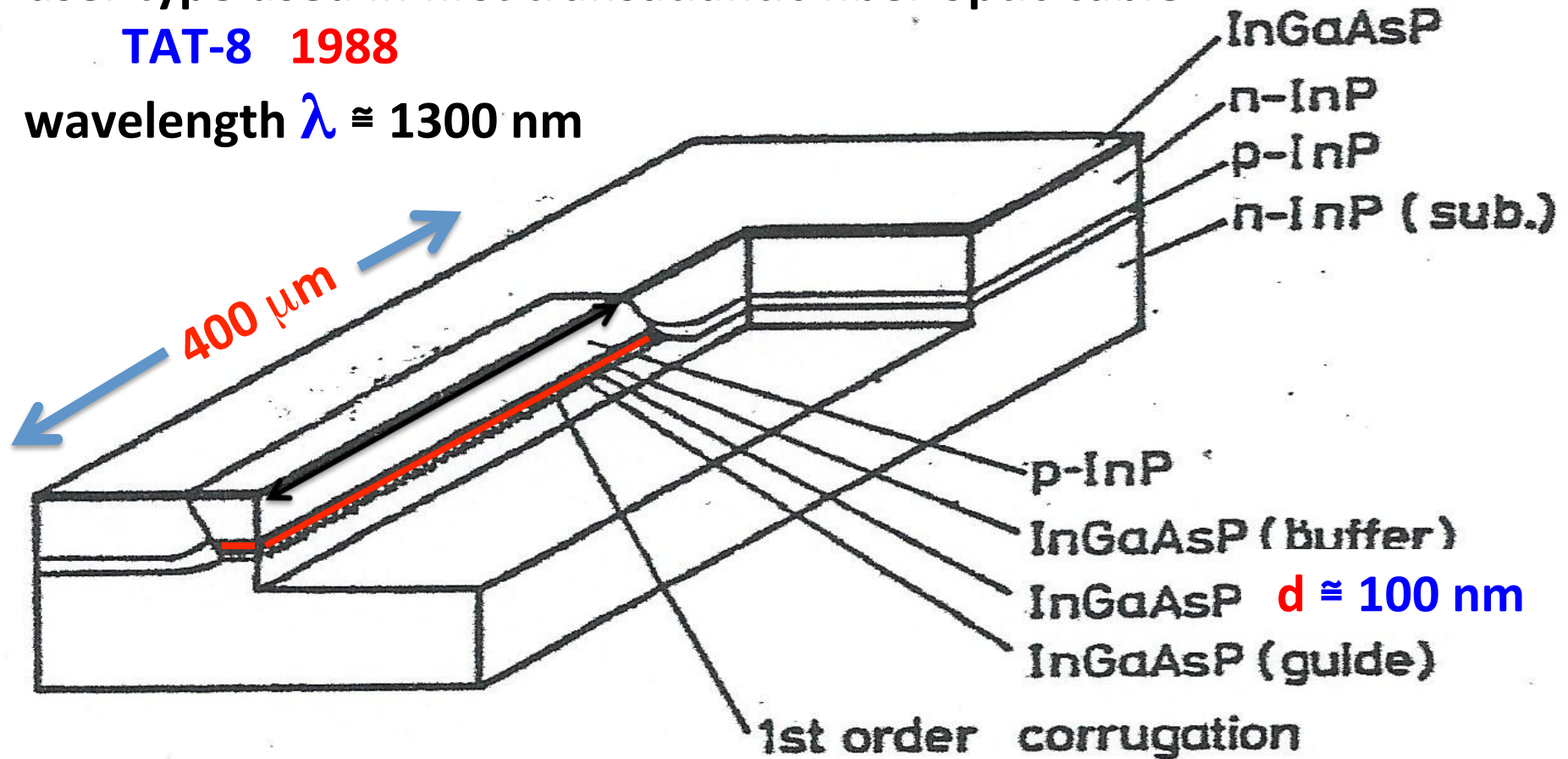
Jrnl Quantum Electronics v11 p436 July 1975

ISLC-9 Buried Heterostructure BH-DFB 1984

Laser type used in first transatlantic fiber optic cable

TAT-8 1988

wavelength $\lambda \approx 1300$ nm



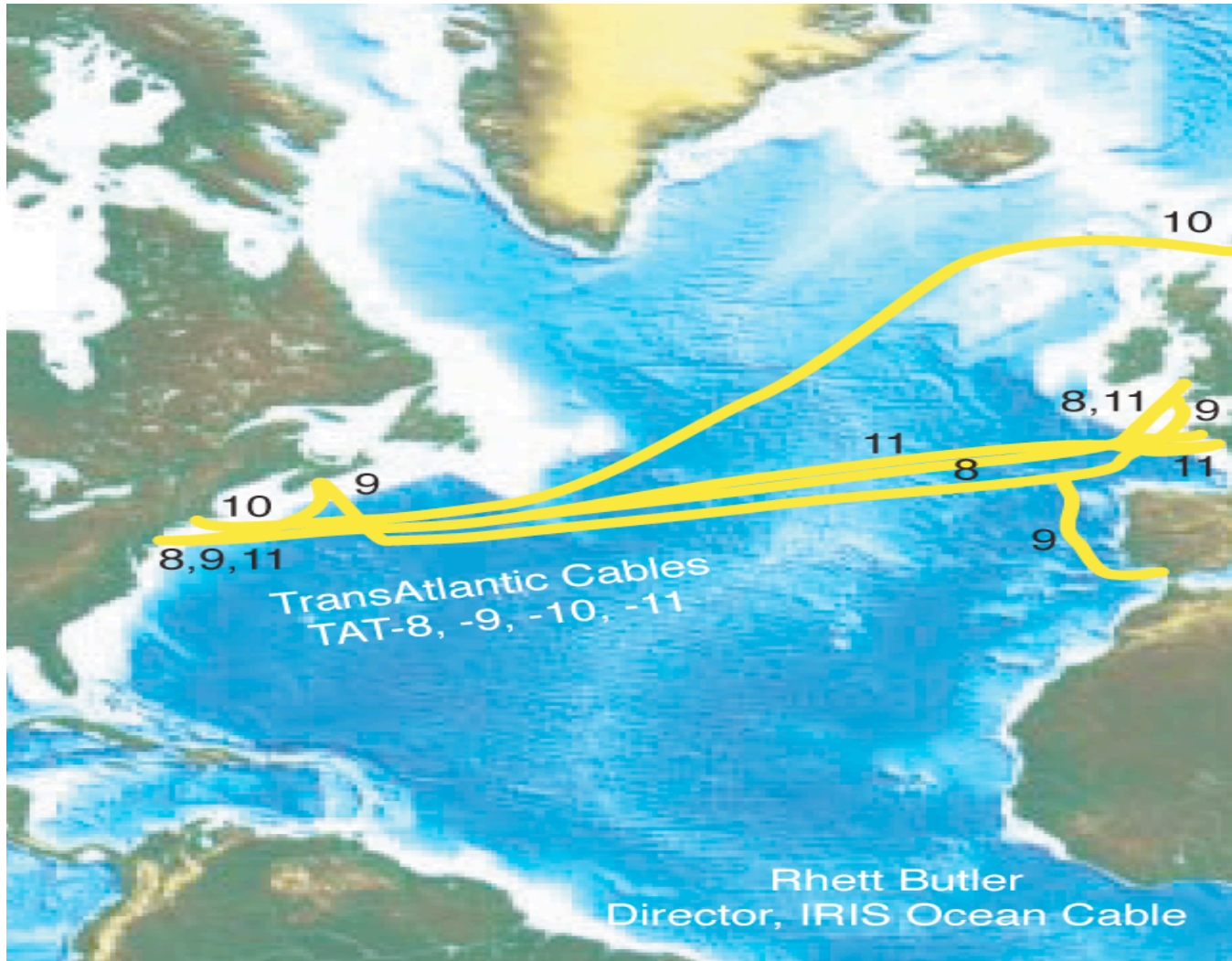
ISLC-9 Rio paper A-1 Hitachi Ltd

“Optimization of Device Parameters for Low I_{th} DFB Lasers”

TAT-8

1988

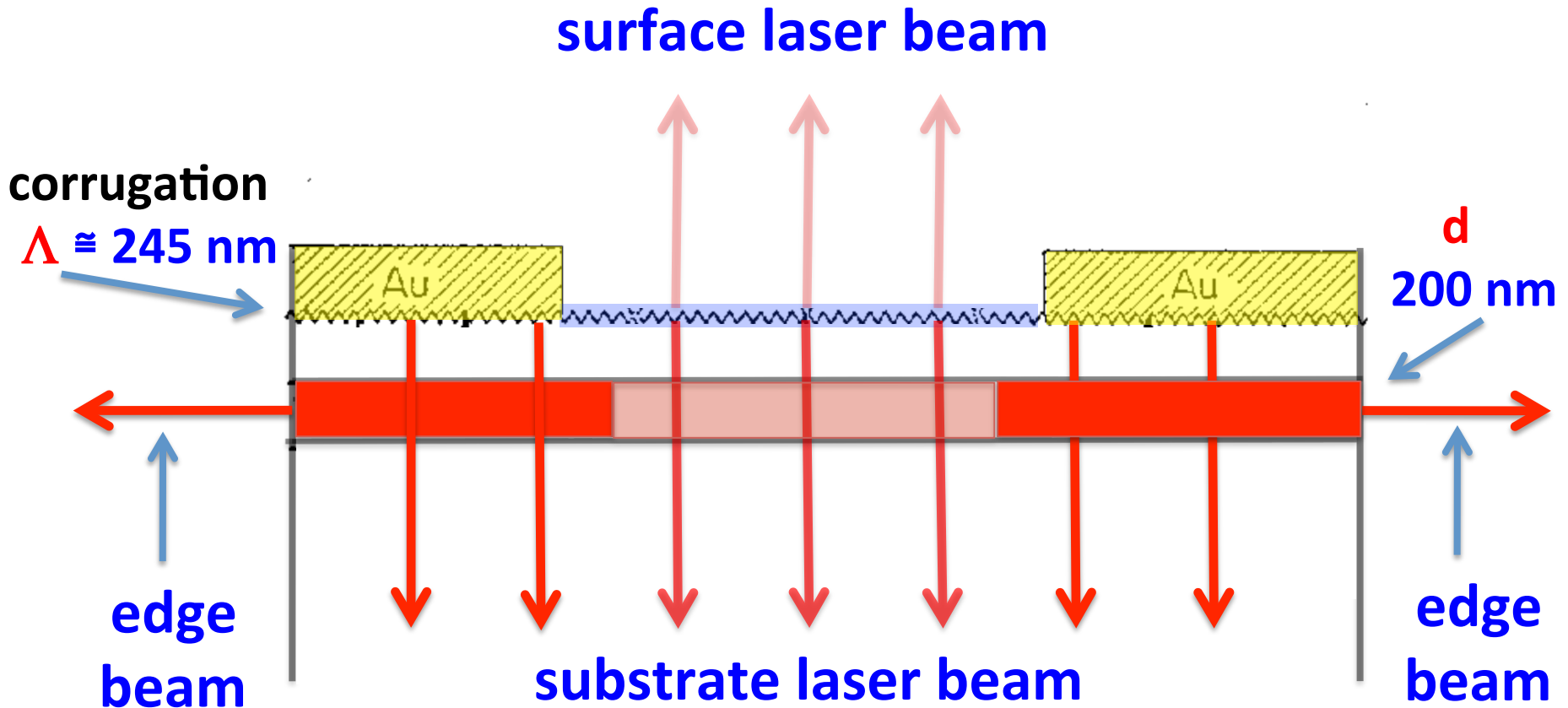
1st TransAtlantic Cable providing telephone service via pulsed laser light



- * **DH** laser reliability: dark-line-defect **DLD** / transient effects
- * **DH** & **SCH** laser performance: optimal **active layer** thickness
- * Cryogenic Lead-Salt lasers operating in the mid-infrared
- * New **2D** waveguide structure
buried heterojunction **BH**
- * New **1D** active region
corrugated waveguide
wide aperture surface emission
Grating Coupled Surface Emitting Laser **GCSEL**

ISLC-4 DH laser - corrugated active region 1974

Grating Coupled Surface Emitting Laser **GCSEL** 300°K pulsed



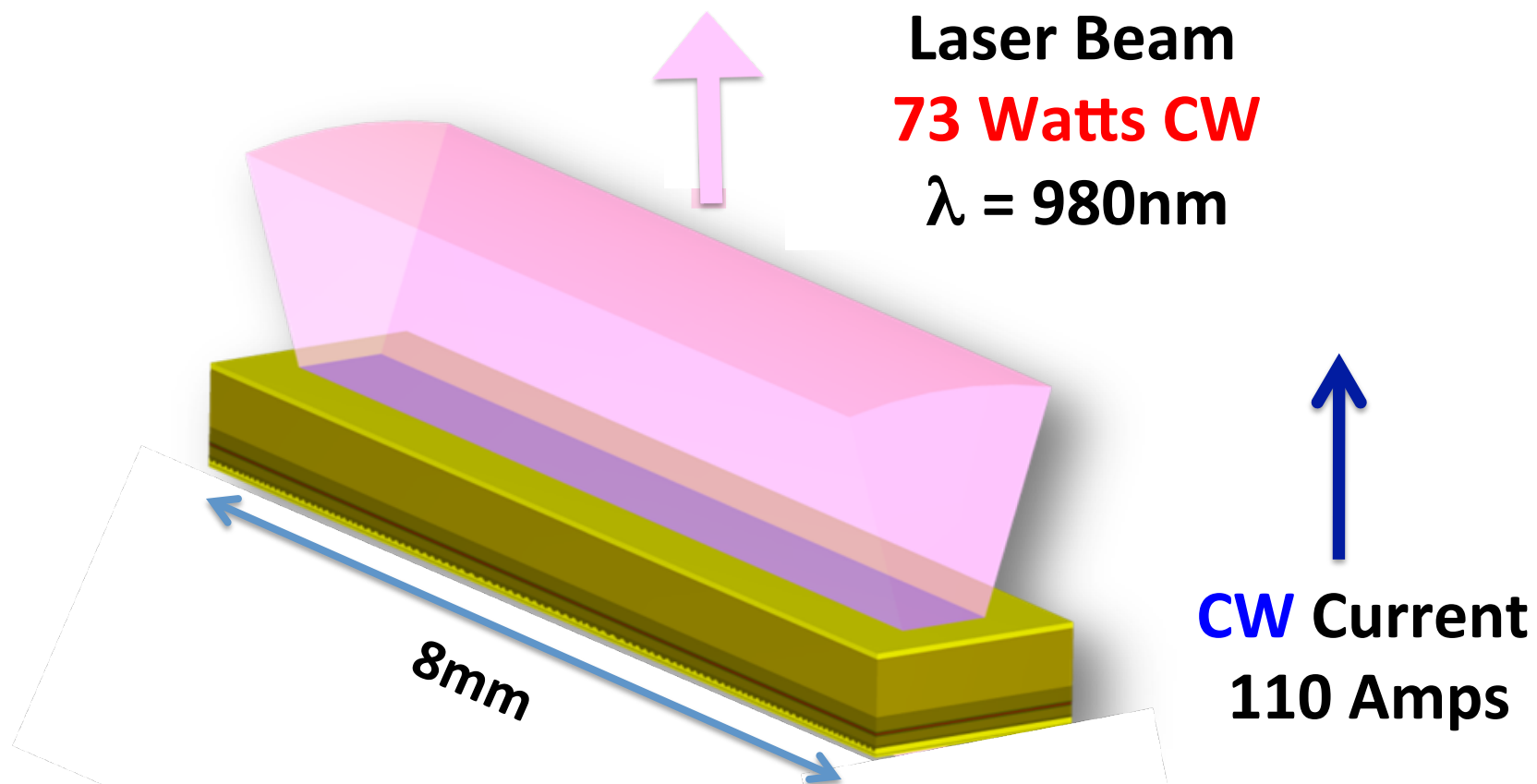
ISLC-4 Atlanta paper PD-2 IBM Research

"Grating Coupled **GC** AlGaAs **DH** Diode Lasers"

Jrnl Quantum Electronics v11 p451 July 1975

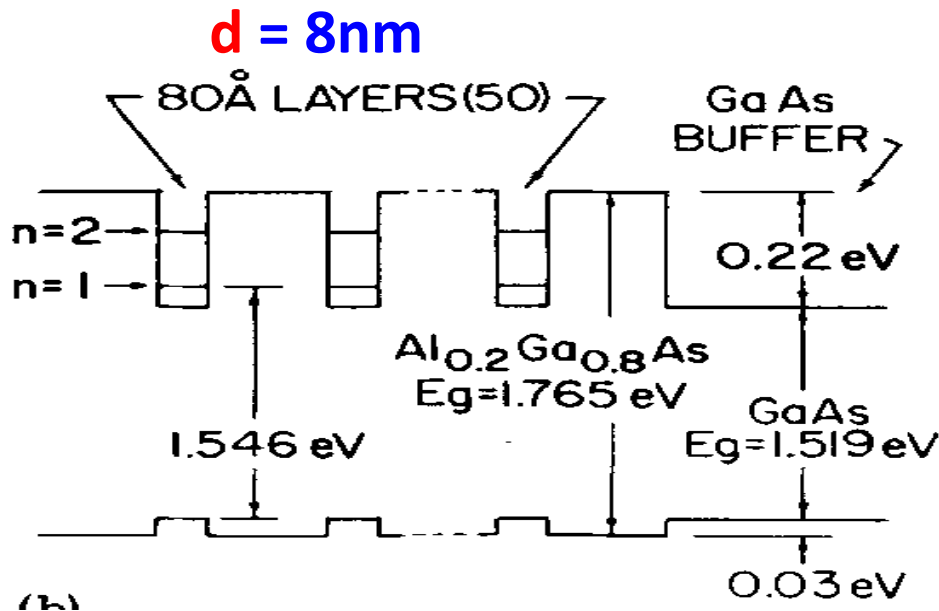
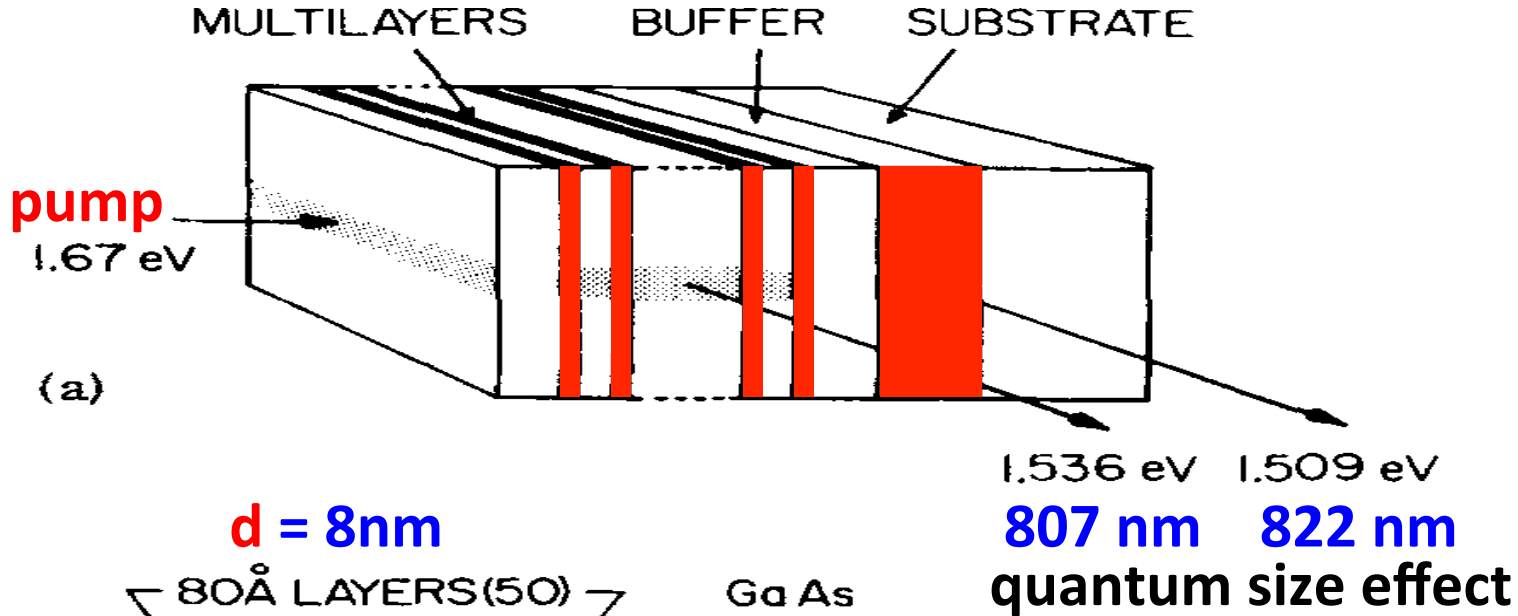
GC Substrate Emitting DFB Laser GCSEL

2010



1st quantum well QW laser

1975



Laser Material
Grown using
Molecular Beam Epitaxy
MBE

ISLC-5

Nemu-No-Sato

1976



*** Elimination of “Kinks” in Output Power vs Current Profiles**

AlGaAs/GaAs Structures for stabilizing **2D** waveguide modes

“Simple” very narrow stripe **2D** waveguides:

gain/loss, implanted ions, dielectric layers

Complex structure **2D** waveguides:

transverse junction stripe **TJS**, embedded, loaded

*** Corrugated waveguide structures:**

single frequency **DFB** lasers / surface emission **GCSELs**

Long distance fiber communication potential

Paper L-V-7 Lincoln Lab USA

“(InGa) (AsP) / InP **DH structure Lasers”**

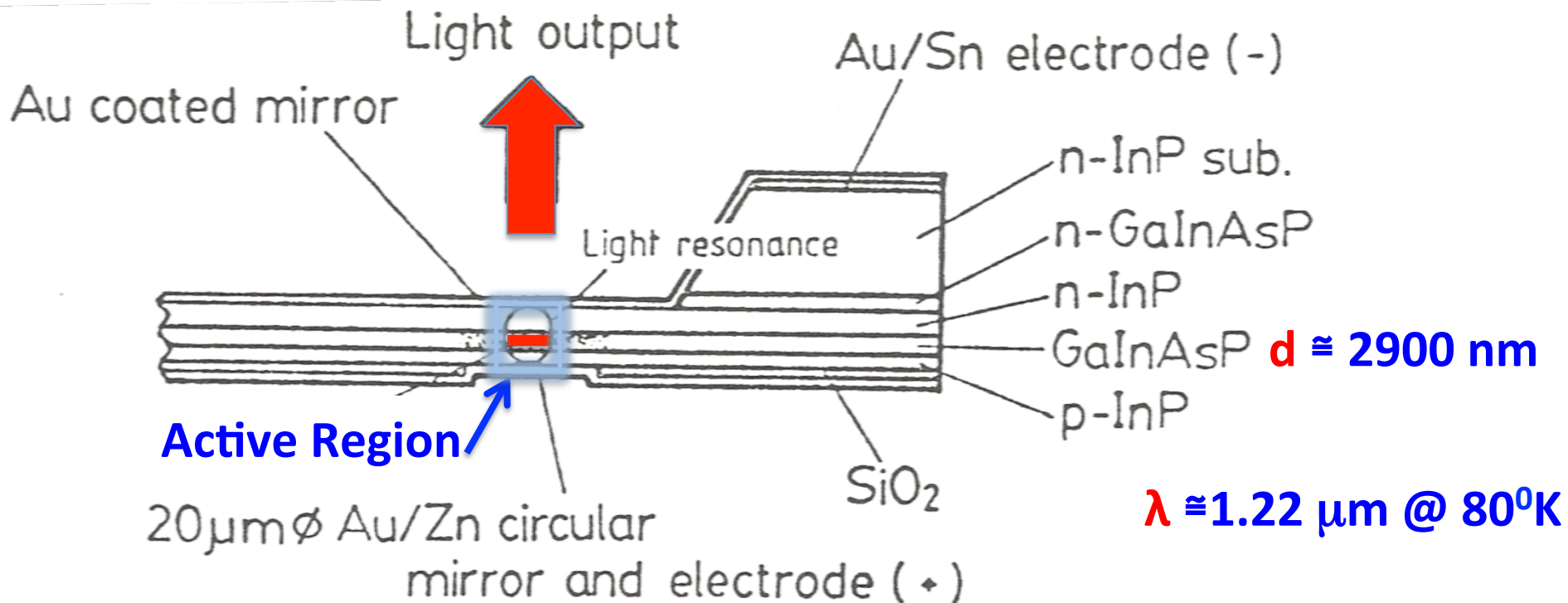
$\lambda = 1.1\mu\text{m}$ @ 300⁰K

Applied Physics Letters v28 p283 1976

- * Long Wavelength **InGaAsP** lasers: $\sim$ 30% of total papers
 - 9 general type papers
 - 9 papers directly related to **temperature sensitivity**
- * Reliability issues:
 - now mostly InGaAsP/InP lasers AlGaAs/GaAs proven
- * Mode hopping noise in single longitudinal mode **SLM** lasers
 - stabilized **2D** waveguide mode AlGaAs lasers
- * **New type of active region**
 - “Surface Emitting Injection Laser”
 - later to be known as the **VCSEL**

ISLC-8 Vertical Cavity Surface Emitting Laser 1982

VCSEL



Schematic view of a surface emitting GaInAsP/InP injection laser with short cavity length

ISLC-8 Ottawa paper 37 Tokyo Inst Technology

"SLM Oscillation of 10 μm cavity-length Surface Emitting Injection Lsr"
Japanese J Appl Phys v18 p2329 1979

ISLC-9 Rio de Janeiro Discussion Topics 1984

- * **Most controversial issue**

What's the best **SLM** structure for long distance optical fiber communication systems? the **CHIRP** problem
present modulation bandwidth $\sim 10\text{GHz}$

- * **Most Popular topics:** 15 papers each
high power and single longitudinal **SLM** mode lasers

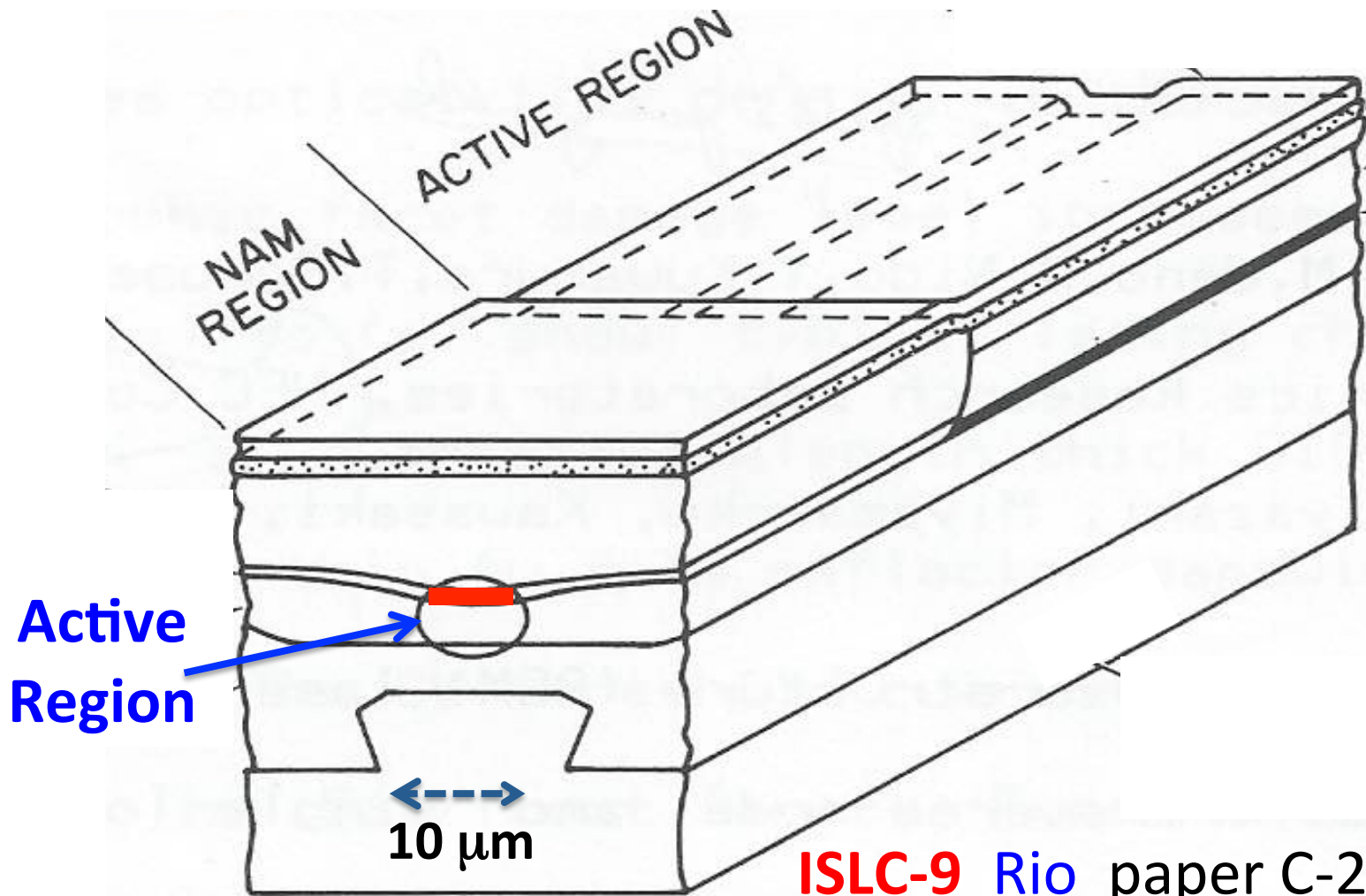
- * **Quantum Well **QW** lasers:** 9 papers
Temperature dependence of threshold **T_0**

- * **High Power**

Non-absorbing mirror **NAM laser**
1.5 Watt - 100ns pulse - high quality beam

ISLC-9 High Pwr Non-Absorbing Mirror **NAM** Lsr **1984**

Constricted **DH** Large Optical Cavity **LOC** Active Region



ISLC-9 Rio paper C-2 RCA Labs

"Non-absorbing-Mirror **NAM CDH-LOC** Lasers"

IEEE Spectrum v22 p43 June 1985

*** Most Popular Topic**

27% of papers had **DFB/DBR** acronym in title; popularity due to both long distance telecom & coherent communications needs

*** High Power:**

first 100mW **VCSEL** - order of magnitude improvement
first strained **QW** laser paper at an **ISLC** conference

*** Quantum Well **QW** lasers**

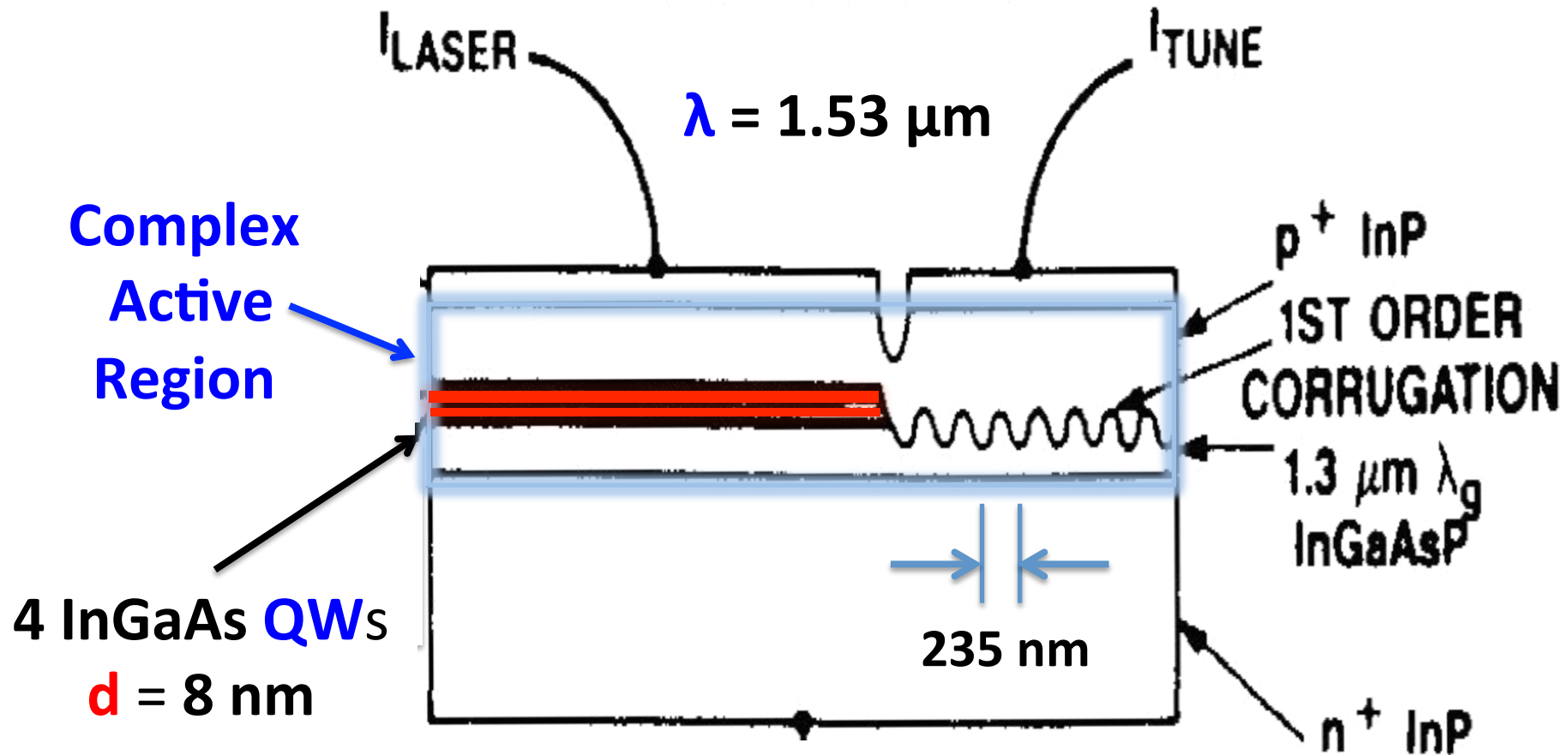
*** High Speed Modulation / Tunable lasers**

high-speed, direct detection,
coherent heterodyne detection systems
wavelength-division-multiplexing **WDM**
photonic Integrated circuit **PIC**

ISLC-11

Tunable MQW DBR PIC

1988



ISLC-5 Boston paper J1 AT&T Bell Labs

“High Performance Tunable $1.5 \mu\text{m}$ InGaAs/InGaAsP **MQW DBR** Lasers”
Applied Physics Letters v53 p1036 1988

ISLC-12

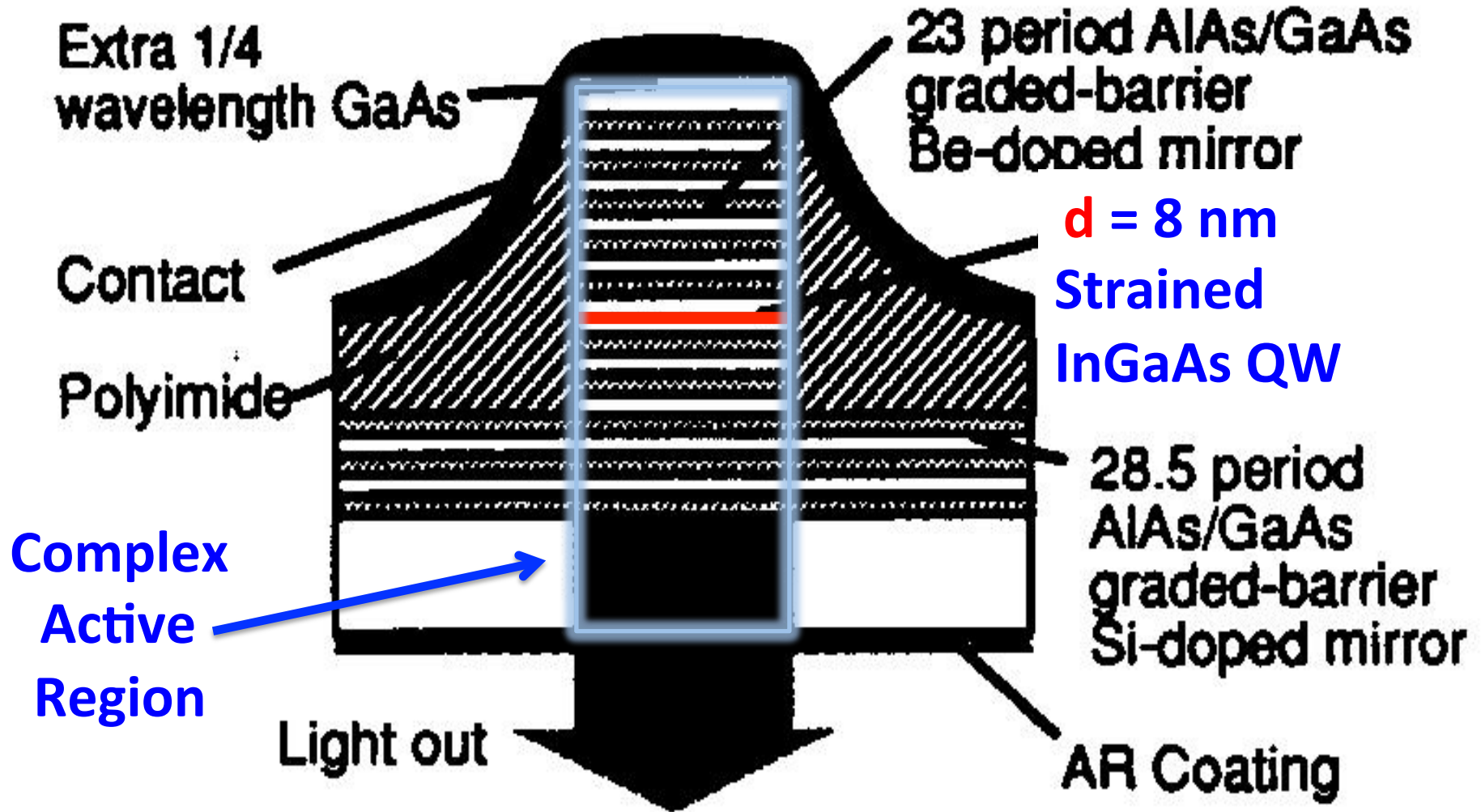
Davos Switzerland

1990



- * The Big Question Not Answered at ISLC-12
Why aren't **QW** lasers as fast as predicted?
- * High Power: **E2** facet treatment process “eliminates”
catastrophic optical damage **COD**
- * Strained **QW** Lasers
 - sub-mA threshold in $\lambda = 1.5 \mu\text{m}$ region
 - InGaAsP/InP laser performance enhanced
using **tensile or compressive** strained **QW**
 - tunable **VCSEL**
 - narrow line-width, single InGaAs **QW VCSEL**
 - sub-mA **CW** threshold at 300⁰K

ISLC-12 CW 300⁰K VCSEL single QW active layer 1990



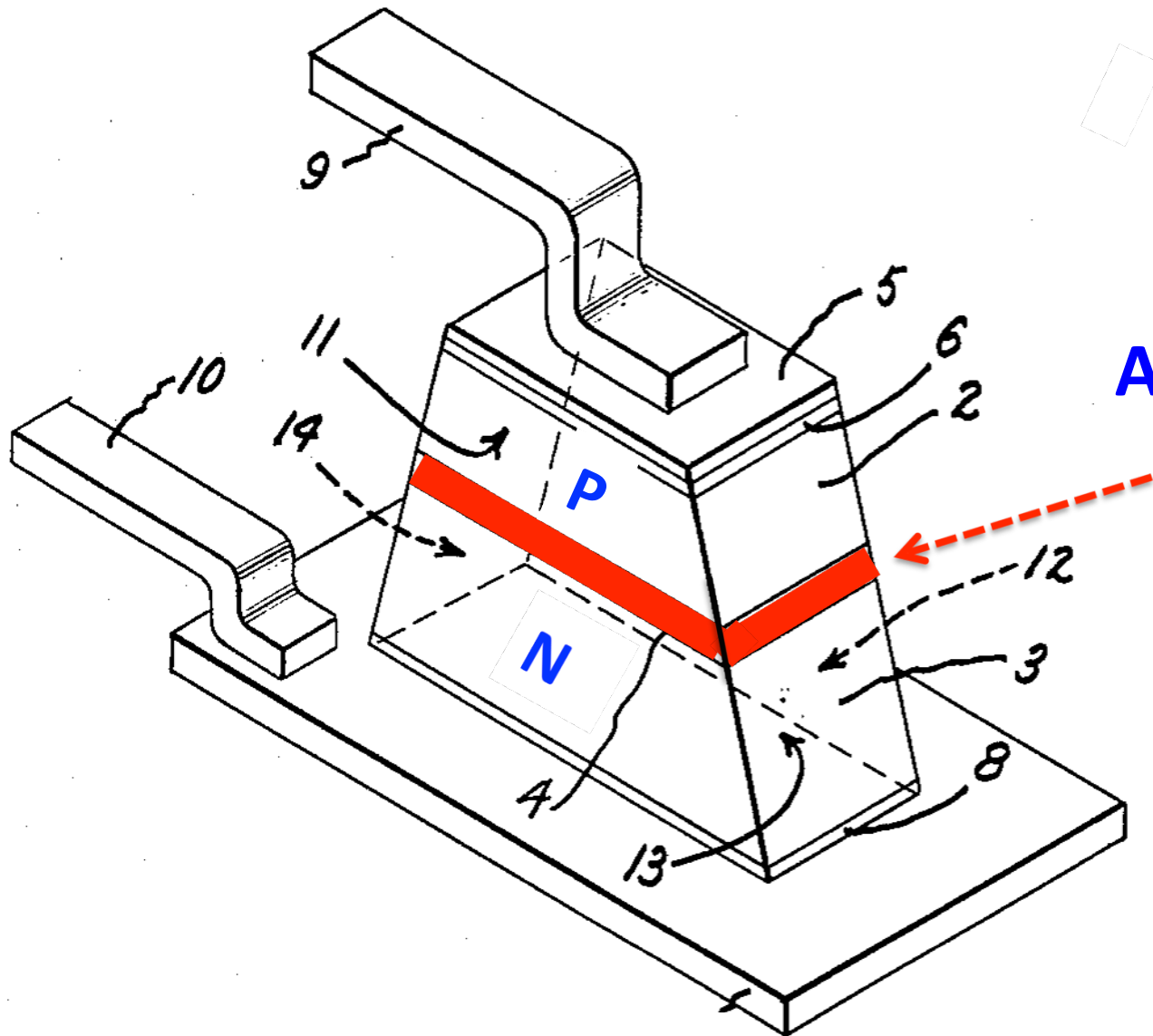
ISLC-12 Davos paper B-1 UC Santa Barbara

“Narrow Linewidth, Low Threshold **VCSELs**”

Applied Physics Ltrs v57 p1605 1990

1st Diode Laser

1962

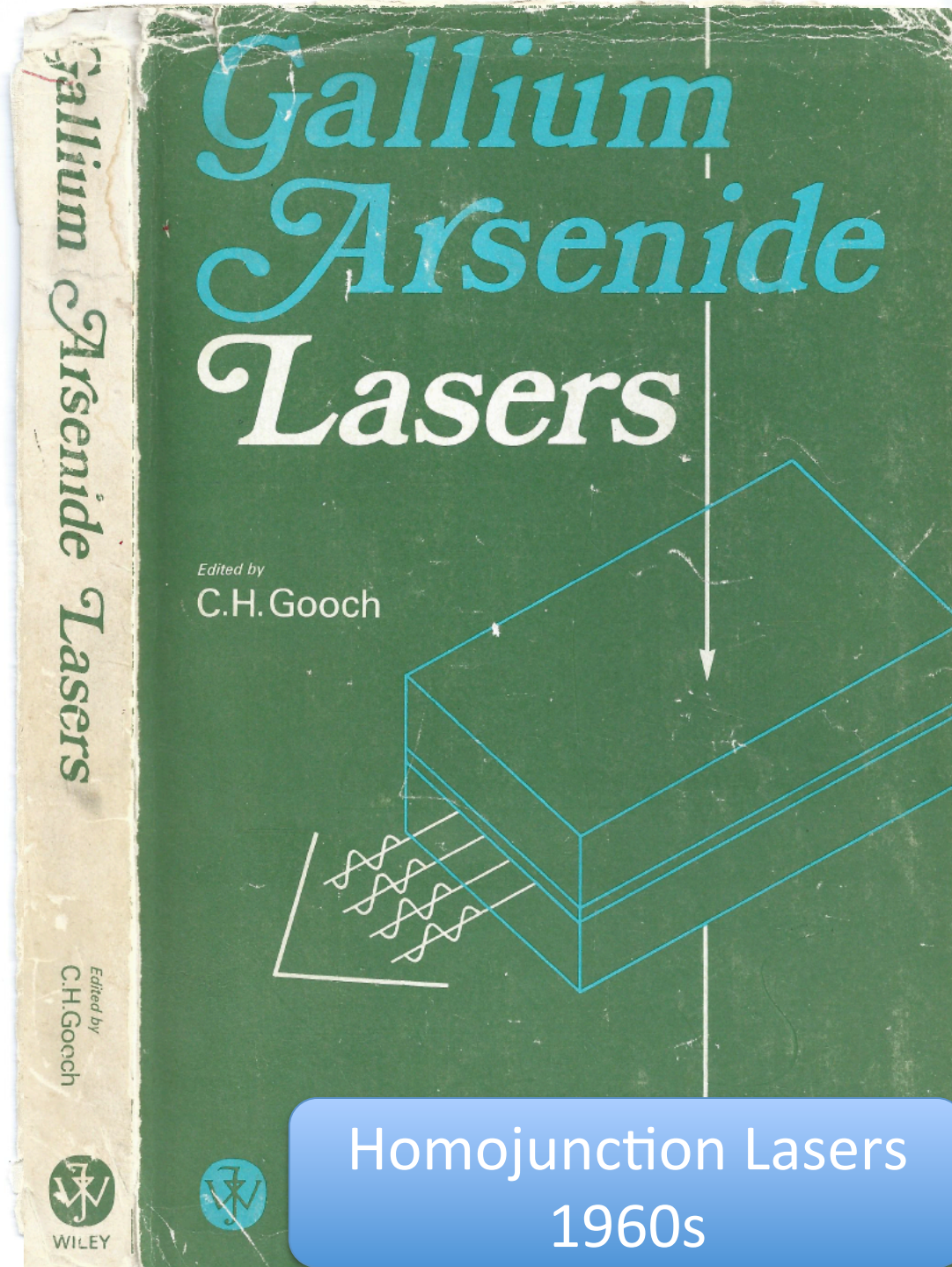


Active Region
 $d \approx 2000 \text{ nm}$

US Patent 3,245,002 filed 24 October 1962 R. N. Hall General Electric

1969

Colin Gooch
UK



Homojunction Lasers
1960s

ISLC International Semiconductor Laser Conference

1967 to 1990

commercially available

#	Year	Active Layer thk 'd' nm	CW Power quality beam reliable mW	Digital Speed Mb/s
1	1967	≈ 2000		
2	'69	≈ 1000		
3	'72	200		0.01
4	'74			
5	'76	100	5	
6	'78			45
7	'80		15	275
8	'82			
9	'84		20	400
10	'86	10		
11	'88		40	
12	'90	5	100	1000