

Thirty Revolutionary Years

How Photonic Innovations Have Changed the World

20th Annual Meeting of the IEEE Lasers and Electro-Optics Society

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WARBURG PINCUS

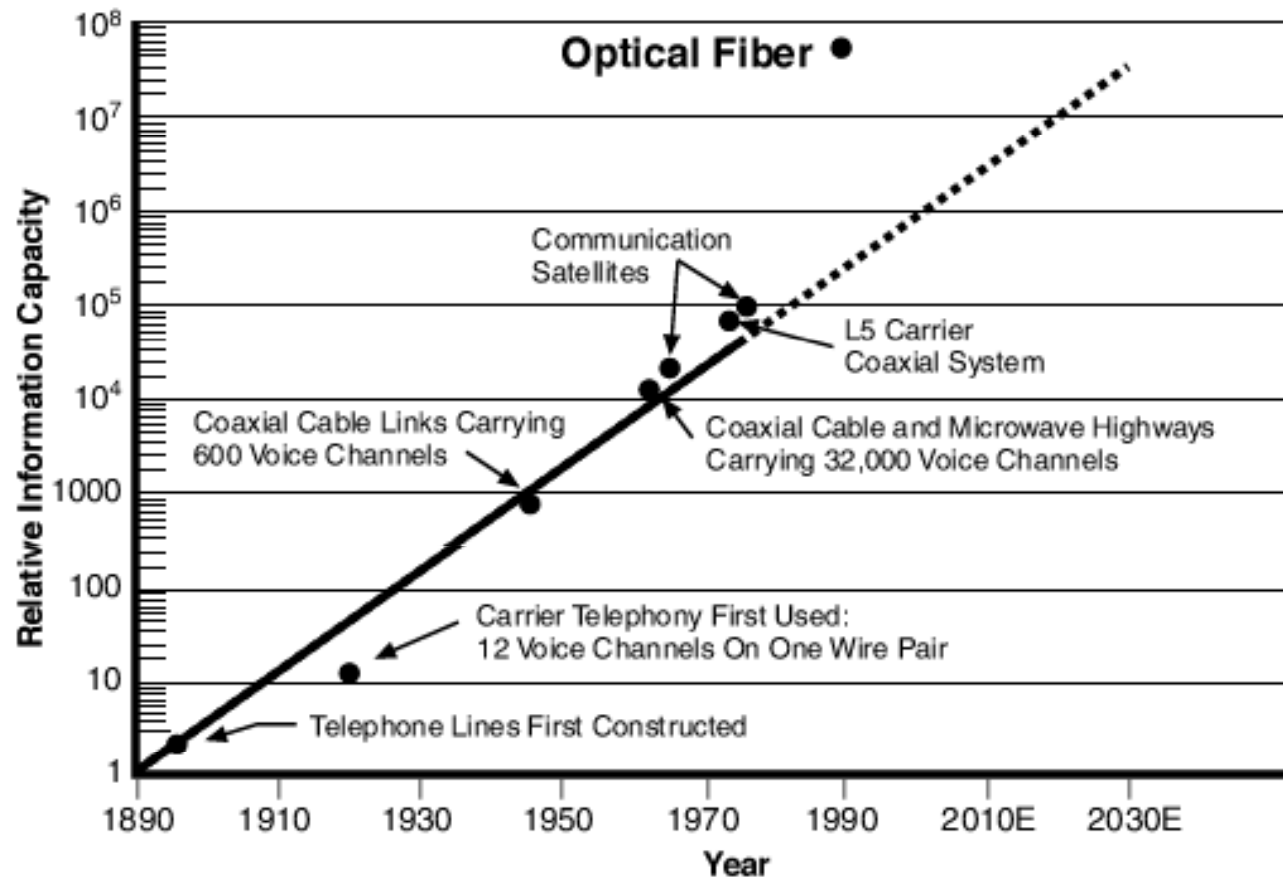
Key Devices Reach the Market: The Building Blocks of the Digital Age

- Magnetic disc storage – early 1960s
- Lasers – early 1960's
- Heterojunction laser diodes – late 1960s
- LEDs – late 1960s
- Integrated circuits: CMOS – early 1970s
- Detectors – mid-1970s
- Liquid crystal displays – 1970s
- Fiber optics – early 1970s
- CCD imagers – mid-1970s

The Impact of Photonics has been Enormous

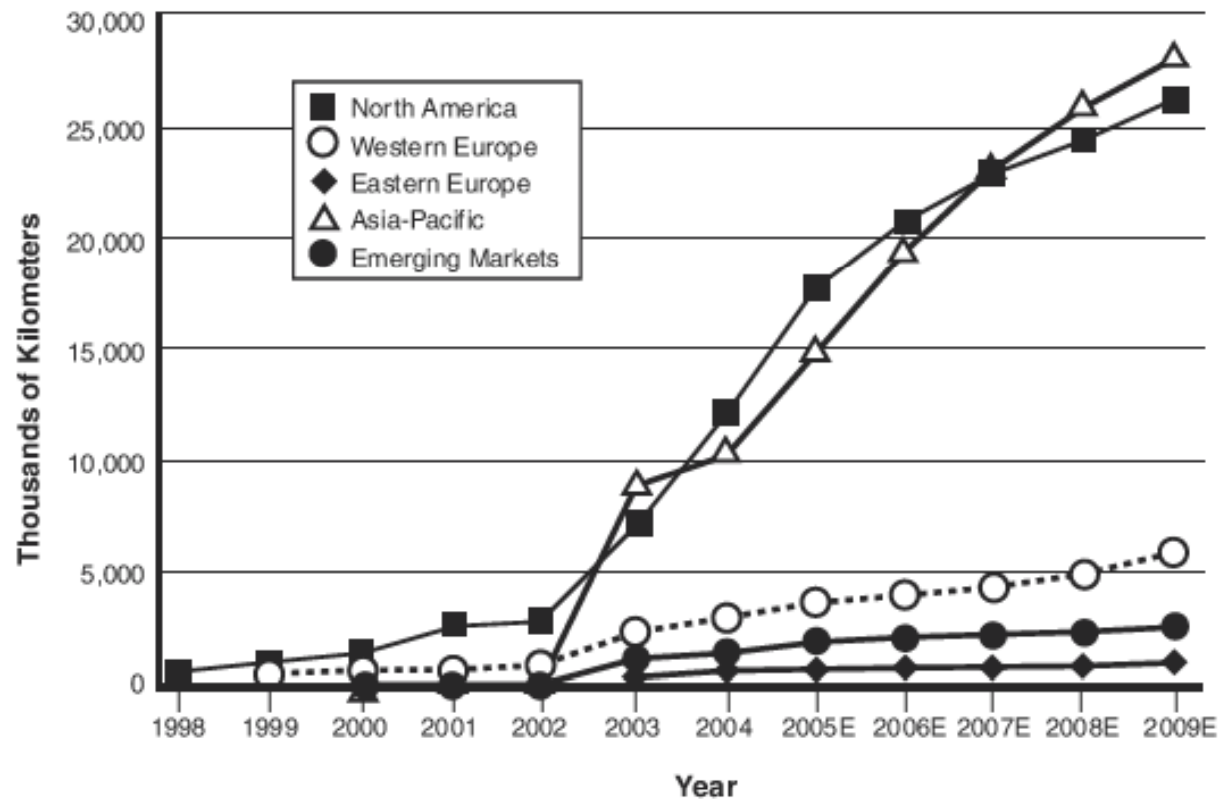
- Optical communications – short and long distance
- Lithographic tools – enabling Moore's Law
- Back lighting for LCDs (e.g., digital cameras, wireless handsets, TV receivers, PCs)
- Storage of Media – DVD, CD
- Efficient light sources – low and high power
- Machining materials
- Military systems – target designation, proximity sensing
- Medical procedures (LASIK and many others)
- Instrumentation of all kinds (e.g., barcode readers, gas sensors, many others)
- Scientific applications

The Optical Fiber Communications Revolution



Source: From *Lasers: Invention to applications*, National Academy of Sciences

Low Absorption Optical Fiber Demand by Region*



Source: KMI Research

(*Values beyond 2004 are estimated)

Communications: The Impact of Photonics

- Fiber optics deployment enabled the Internet and broadband consumer access
- Consumer broadband access dramatically changed consumer services
- Systems allow the linkage of the world's economies: key element for industrial globalization
- Cellular wireless handsets are impractical without LCD LED back lit displays

Industries Transformed and New Ones Emerge

- Communications industries transformed by new competition (cable, wireline and wireless operators compete for similar services)
- Entertainment industry transformed by new DVD and Internet distribution – turmoil in revenue models
- With low cost LCD displays, consumer products move to hand-held devices: Consumer electronics become hot growth business
- The cell phone becomes ubiquitous – over 2 billion in use world-wide

The Globalization of Industries

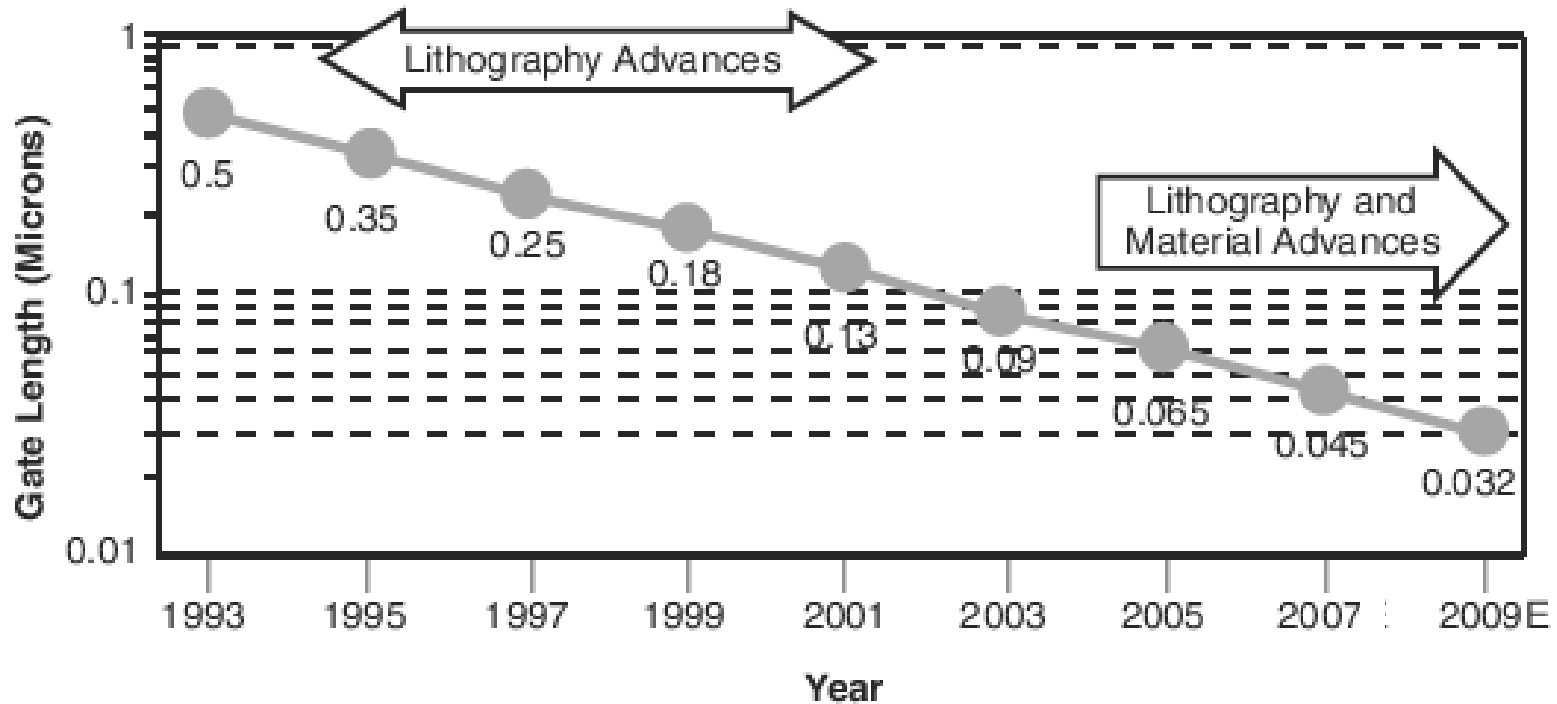
- Fiber optic communications are deployed world-wide forming the nervous system of the world
- Seamless “instantaneous” supply chains enabled by high data rate communications make distributed manufacturing economical
- Product development can be linked through remote sites: Software outsourcing to India and emerging countries became practical

Result: Corporations become global with distributed manufacturing and R&D.

Lasers Enable Integrated Circuit Production

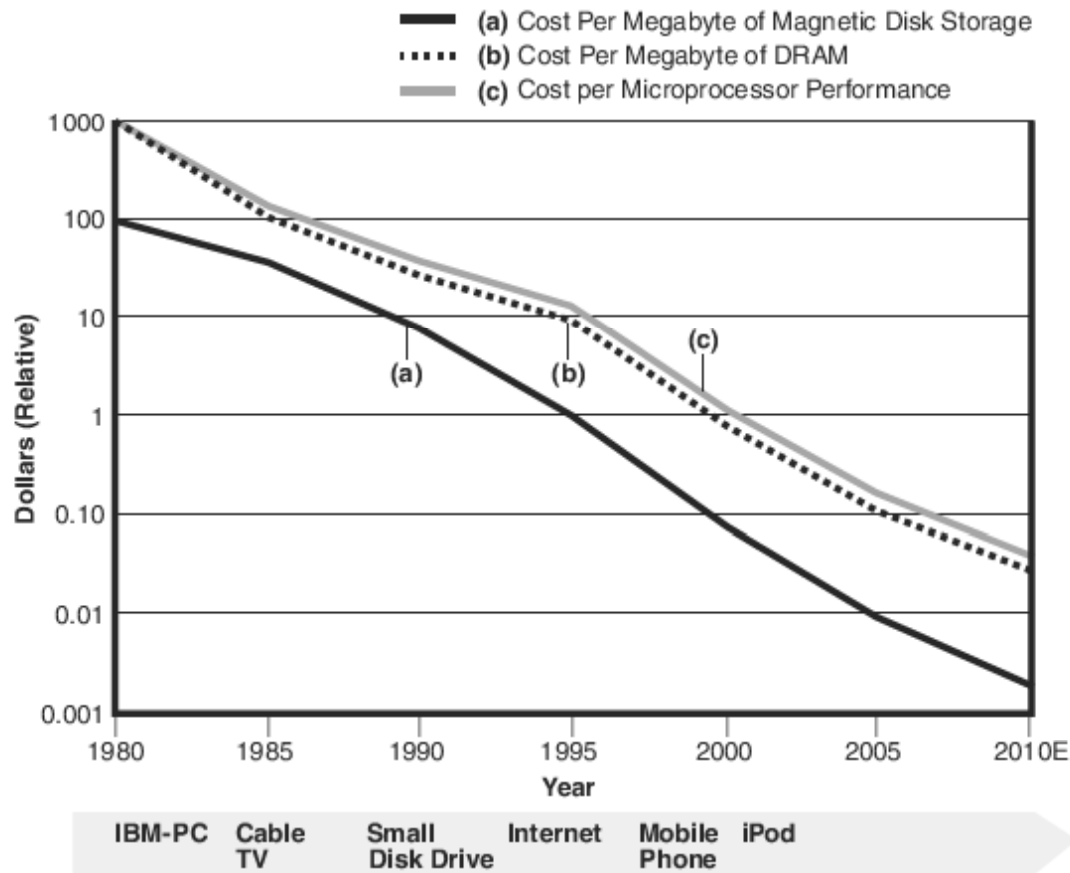
- Impossible to make devices below about 0.5 micron features with ordinary light sources
- Excimer lasers are key light sources in lithographic equipment for IC production
- Without lasers, Moore's Law would have stopped – X ray and electron beam alternatives are very difficult and costly technologies for lithography

Lasers Enable Moore's Law



Source: Courtesy of Intel Corporation and UBS estimates

Historical Relative Cost of Magnetic Disk Storage, DRAM and Microprocessors used in Computing Systems

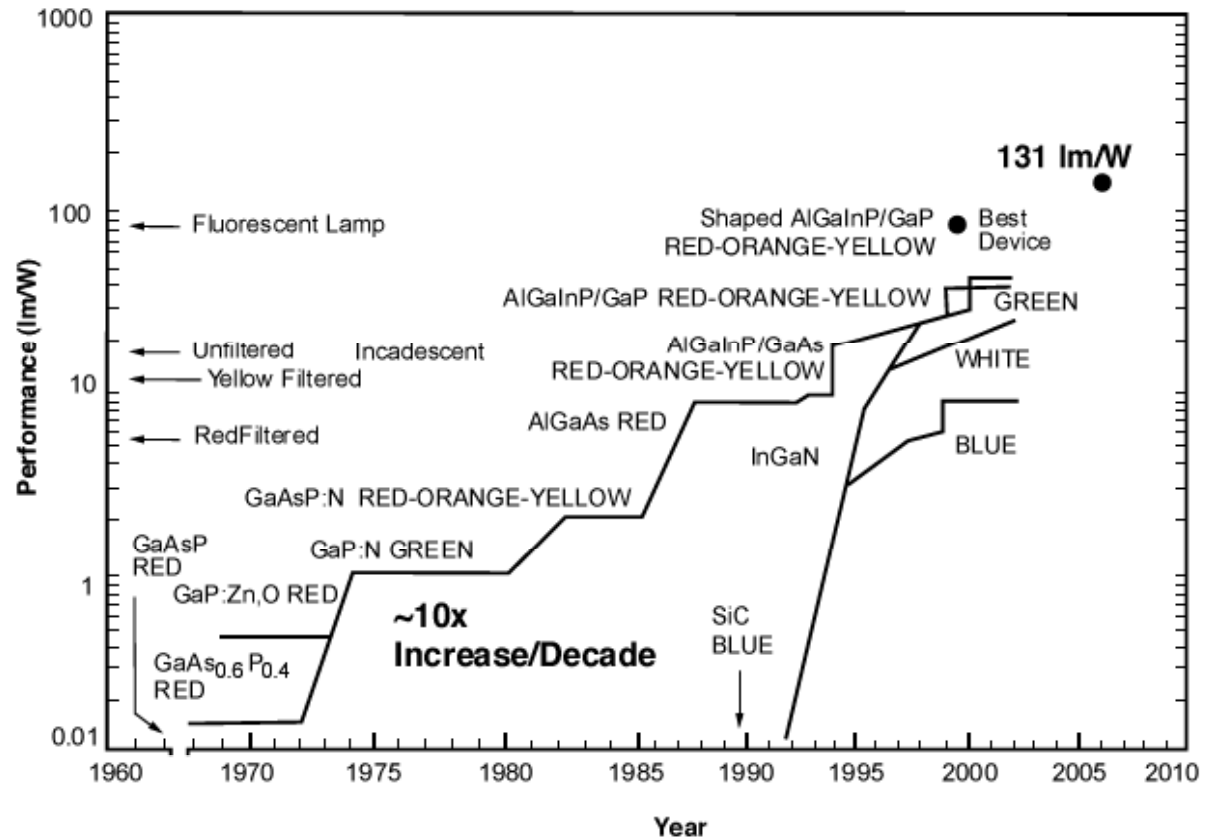


Source: TechViser

LEDs are Everywhere

- LEDs are ubiquitous miniature indicators
- LEDs are used for backlighting liquid crystal displays
- Organic light emitting diode displays offer unique alternatives to LCD displays
- LEDs are expected to gradually replace less efficient and reliable light bulbs and fluorescent lamps as costs decline

Progress in LED Performance



From F.M. Steranka, et al., "High power LEDs: Technology status and market applications," *physica status solidi (a)* 194 (2002), 380-388.

A Triumph of Materials Science: The Power of Applied Research

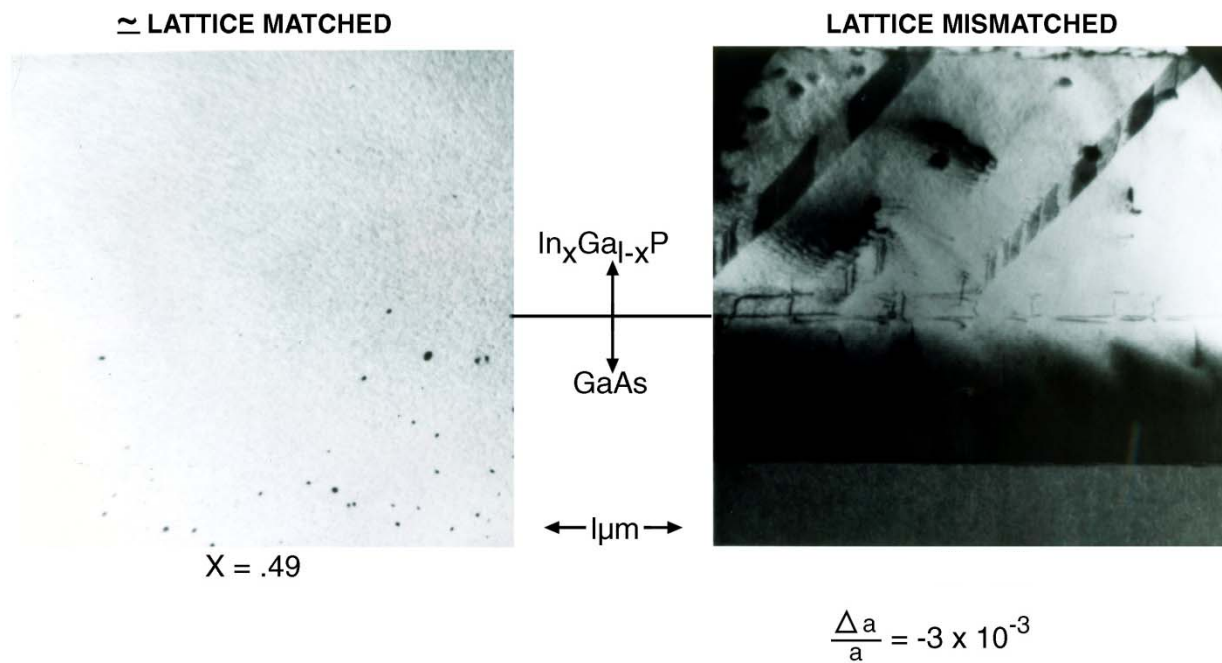
- New materials invented — atomic engineering allows tailoring of properties
- New technologies emerged for large scale production of new materials
- New understanding of crystal defects and their electronic impact made mass production possible
- New ways of improving reliability were discovered to solve seemingly impossible problems

**Extraordinary speed in moving from
concept to production.**

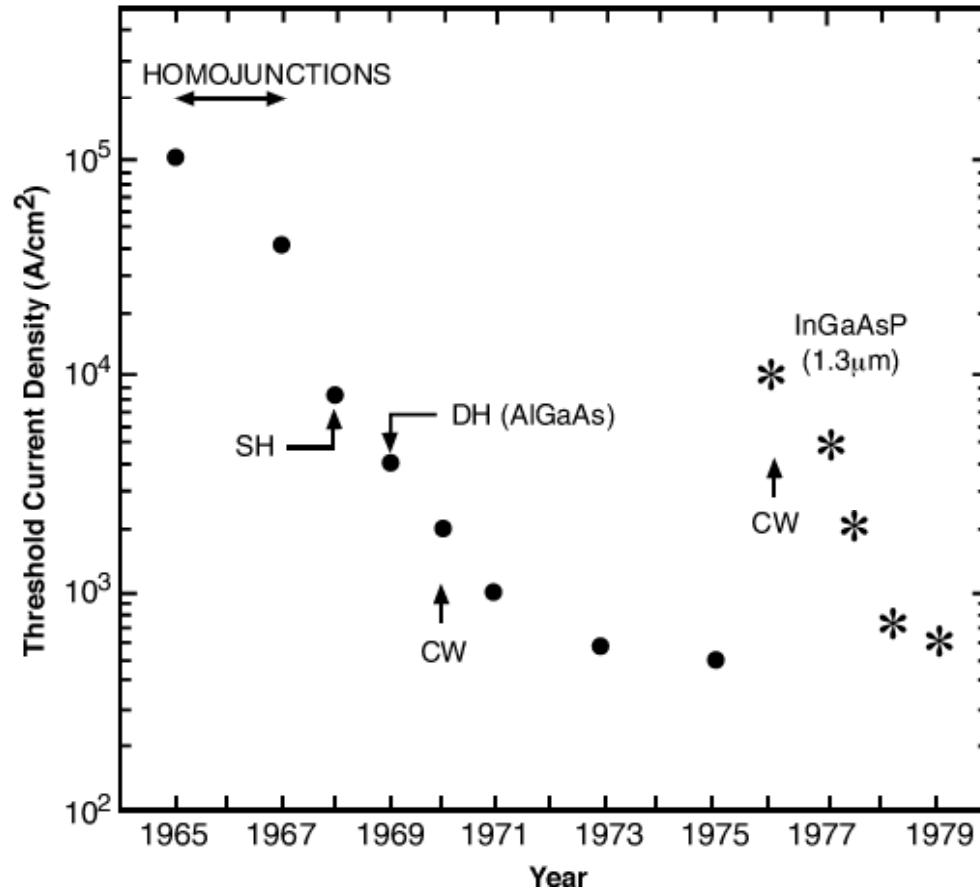
The Semiconductor Laser: From Concept to Product

- Exciting laboratory curiosity in the early 1960s but useless: Unreliable, limited emission wavelength, high current-driven short pulse operation
- AlGaAs/GaAs heterojunction lasers introduced in late 1960s changed everything — enabled practical applications
- Using novel materials, practical laser diodes now range in emission wavelength from the far infrared into the blue
- **BUT** years of hard work needed to get reliable, reproducible, low cost devices for mass markets

Dislocations Kill Radiation Efficiency: Defect-free Heterojunction Interfaces Essential



The Dramatic Historical Reduction in Threshold Current Density



The U.S. Government was RCA's First Customer



ECOM

Sponsor....USA ECOM, Philadelphia
Technical Advisor....USA ECOM, Fort Monmouth
Contractor....RCA Corporation

High Power GaAs Laser Diode



Performance Features

- 60 Watts Peak Power Output
- Emitting Width 55 Mils
- Room Temperature Operation

Applications

- Range Finder
- Secure Communications

Mil. Spec.

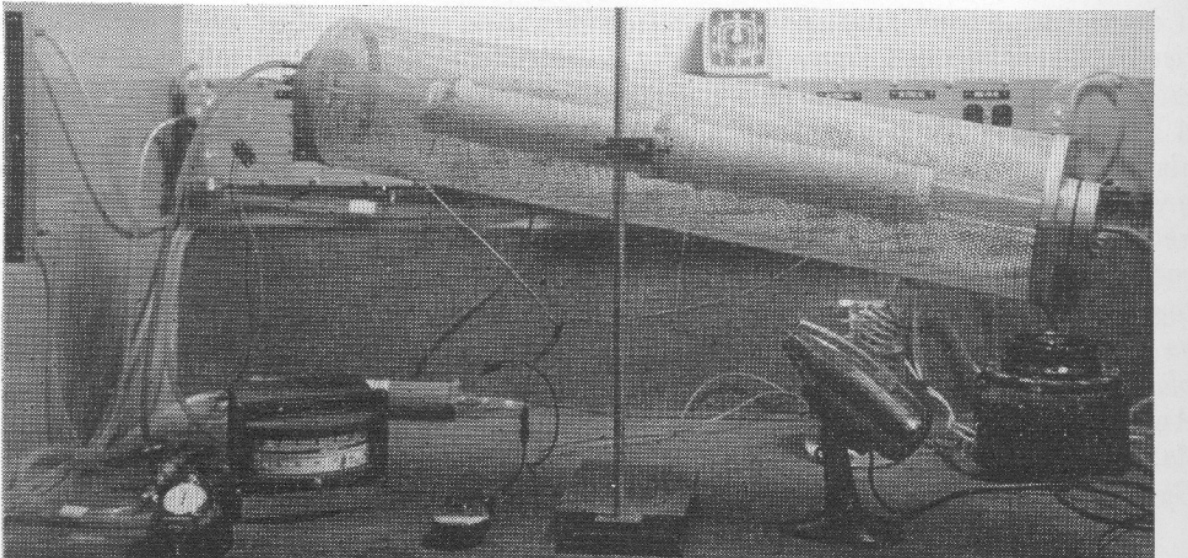
- EL-CP2000-002A

**First used in air-to-air missiles and infantry
weapon simulation.**

The First Commercial AlGaAs/GaAs Heterojunction Laser Diode (Pulsed Operation)



Humble Beginnings of Liquid Phase Epitaxy



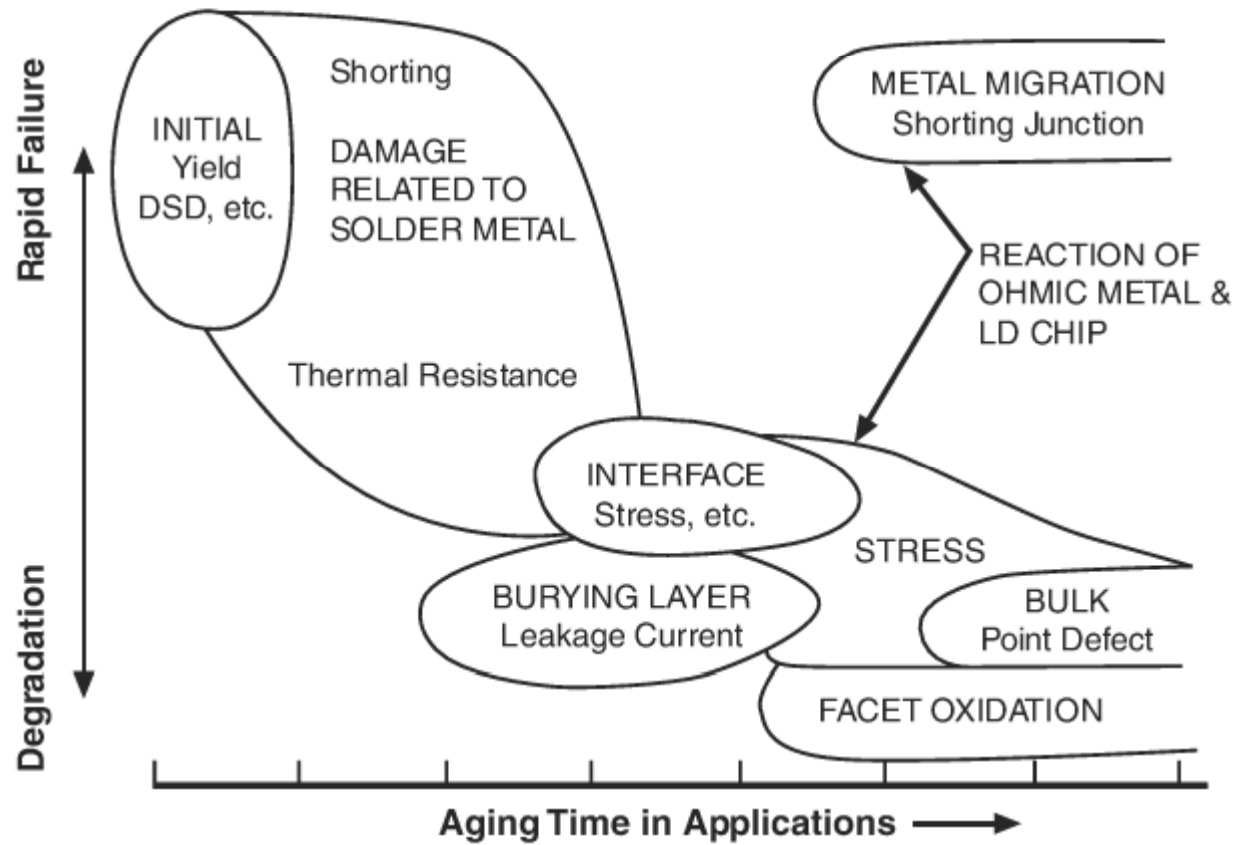
Early growth apparatus for liquid phase epitaxy of semiconductor lasers developed at RCA Laboratories in the early 1960s. From Nelson, "Epitaxial growth;" Photo courtesy A. Magoun, David Sarnoff Library

Automated Fabrication Equipment used to Manufacture Semiconductor Lasers

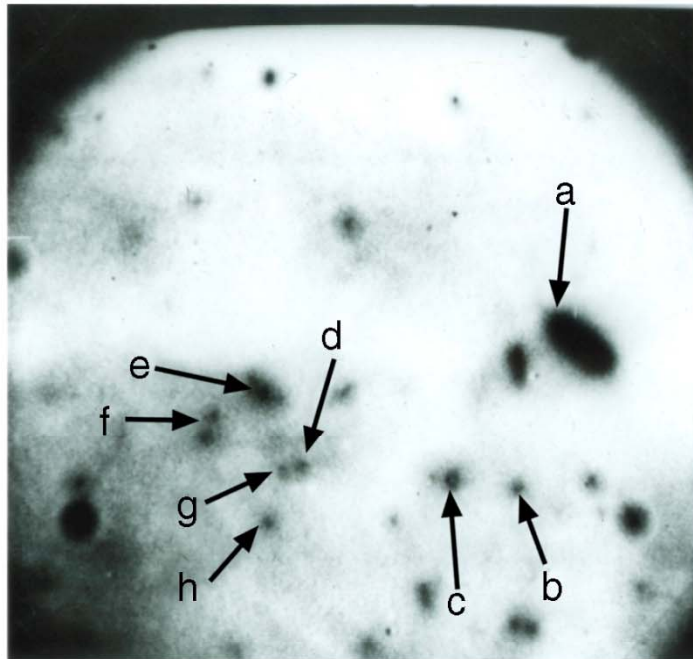


Photo courtesy of Sarnoff Corporation

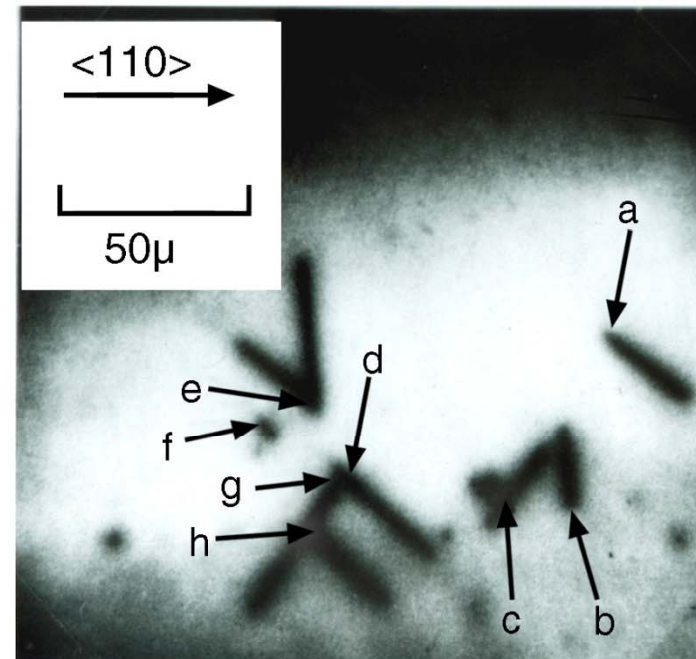
Failure Modes



Degradation due to the Growth of Dislocation Networks in Operation



(a) Start



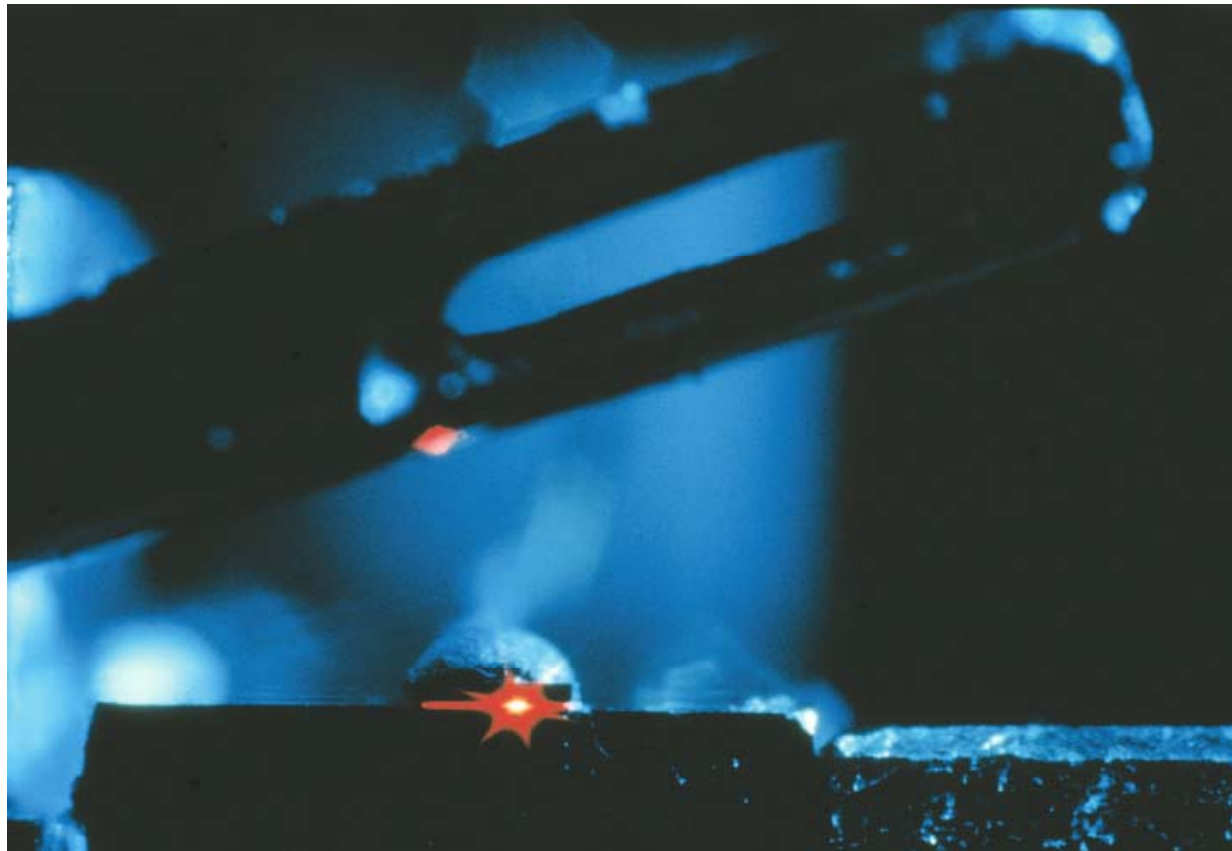
(b) After Operation

Mastering Crystal Defects Saved the Field of Laser Diodes

- Discovery of unpleasant new phenomena – non-radiative recombination enables atomic migration: Solved by control of defects in lasers
- Discovery of facet damage related to optical power density: Solved with facet coatings (material dependant)

A good story ending: Both problems solved enabling mass production and widespread use.

Red-emitting AlGaAs Laser Diode



Commercial Laser for Optical Communications

An RCA Solid State Laser that fits through the eye of a needle can transmit 500 million bits of information per second through a thread of glass.

The entire contents of a 24-volume encyclopedia in 3 minutes. 2500 phone conversations or 20 TV programs at the same time. Staggering amounts of information – all made to pass through a tiny thread of glass by a solid state laser that radiates light from an area one-hundredth the size of the period at the end of this sentence. The laser, developed by RCA scientists, emits a narrow, intense beam of light that can be efficiently coupled into the microscopic fibers that carry the information. Because of its incredible stability and small size, RCA's solid state "double dovetail" laser represents a significant step toward faster, smaller, more efficient fiber optic communications systems.

The Solid State Laser is a product of RCA research – the kind of dedicated research that has been a tradition at RCA ever since Nipper started listening to His Master's Voice. Today, research and development of electronic products are funded at the highest level in our company's history. Our commitment is, as it has always been, to the advancement of technology – to the creation of products that expand the human horizon, whether through a wave of sound or a thread of light.

©1980 RCA Corporation

RCA
A tradition on the move

Key Events that the World would have missed without Photonics

- No Internet and related revolutionary transformations
- No high data rate global communications and VoIP
- No ubiquitous broadband wireless cellular communications such as digital subscriber loop (DSL) service
- Much slower globalization of manufacturing and distribution of development activities
- No massive disruption of the entertainment industry
- No turf wars between cable, wireless and wirelines service providers for voice, video and data services

Conclusions

- From modest seeds great trees grow.
- Complementary innovations lead to unexpected consequences.
- Understanding of physical processes continues to be key. The industrial world is *not* all software.
- The impact of photonics far exceed expectations of 40 years ago.
- We have not seen the end!