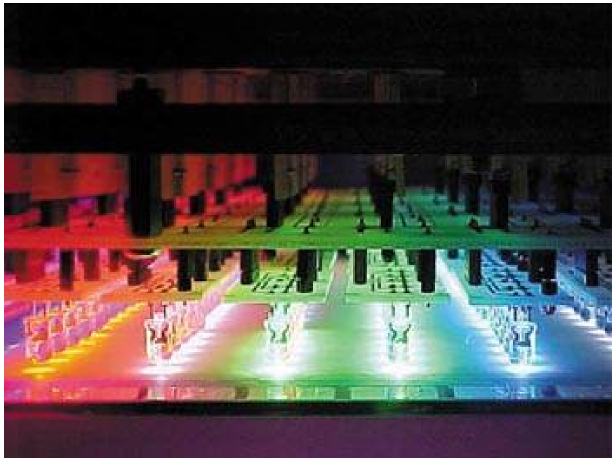
Blue, Green & White LEDs and Blue Laser Diodes

Shuji Nakamura
Solid State Lighting and Display Center
Materials and ECE Departments
University of California, Santa Barbara
www.ssldc.ucsb.edu

The Advantage of LED Lighting

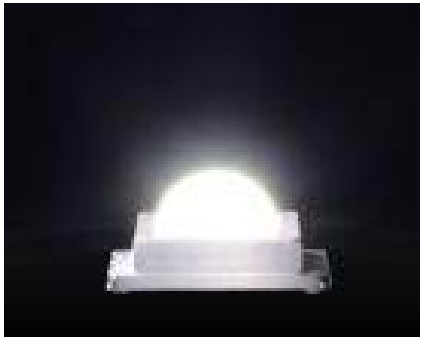
Long life – lifetimes can exceed 100,000 hours as compared to 1,000 hours for tungsten bulbs



Robustness – no moving parts, no glass, no filaments

Size – typical package is only 5 mm in diameter

Energy efficiency – up to 90% less energy used translates into smaller power supply

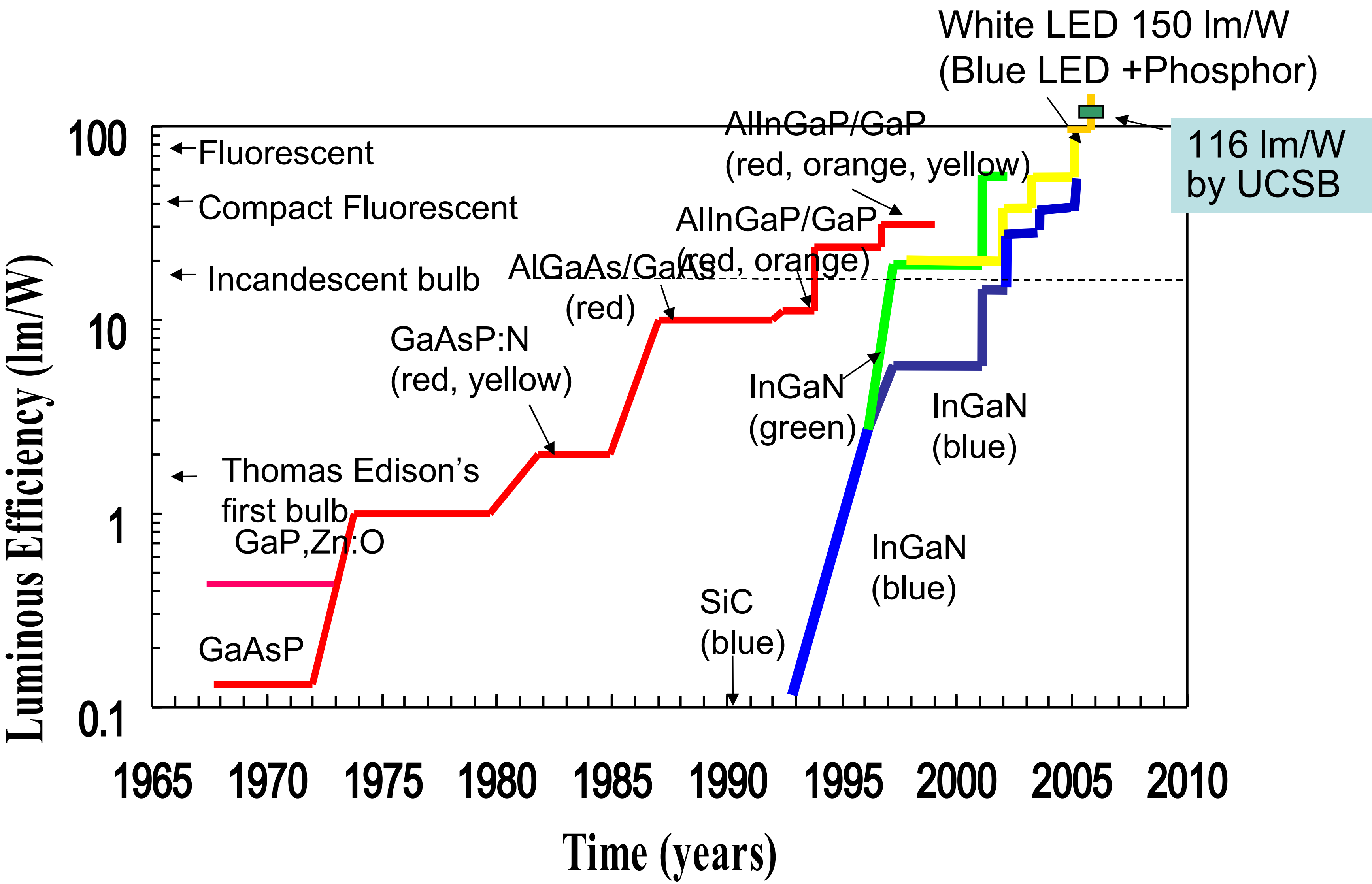


Non-toxicity – no mercury

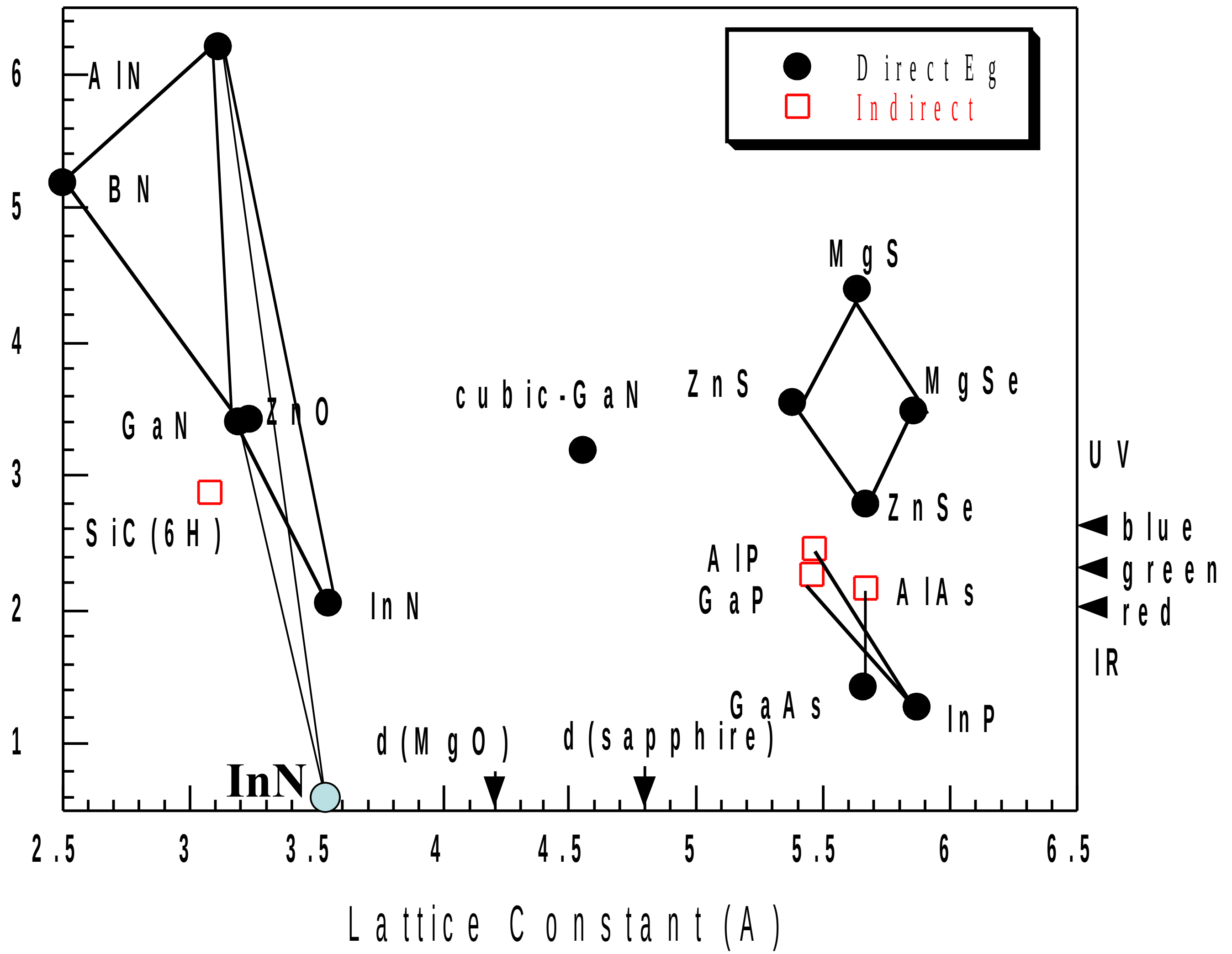
Versatility – available in a variety of colors; can be pulsed

Cool – less heat radiation than HID or incandescent

GaN LED Historical Development



WIDE BANDGAP RANGE



Eg(InN)~0.7

Milestones in the history of gallium nitride (GaN) Research

1971 ~ Maruska and Pankove at RCA demonstrates first blue GaN MIS LED

1986 ~ Akasaki grows high quality GaN using an AlN buffer layer

1988 ~ Akasaki discovers p-type GaN using LEEBI

1989 ~ Nakamura starts GaN growth

1990 ~ Nakamura develops **Two-Flow MOCVD**

1992 ~ Nakamura discovers p-type GaN using Thermal Annealing
(mechanism of hydrogen passivation discovered)

1992 ~ Nakamura successfully grows InGaN single crystal layers

1993 ~ Nakamura demonstrates Bright Blue LED 1 Candela

1995 ~ Nakamura demonstrates first pulsed violet InGaN MQW LDs

1995 ~ Nakamura demonstrates first CW violet InGaN MQW LDs

1996 ~ Nakamura announces Bright White and Green LEDs

Long and Difficult Research to accomplish the innovation

The biggest breakthrough is an invention of Two-Flow MOCVD

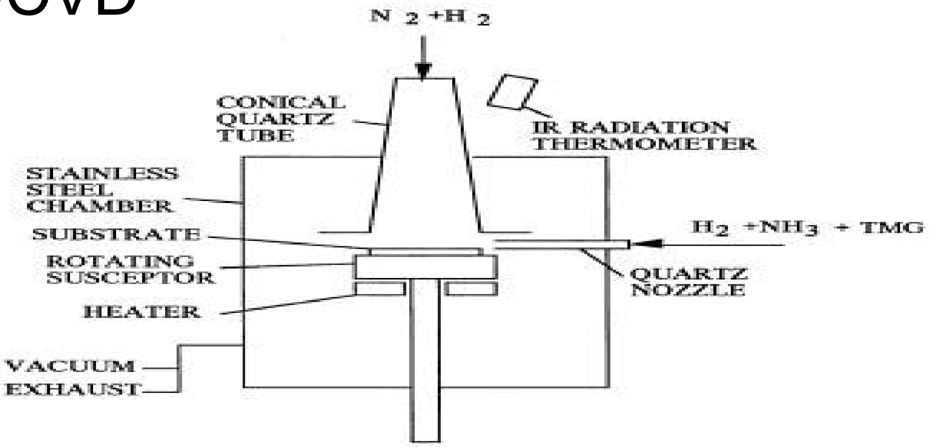


Fig. 1. Schematic diagram of novel MOCVD reactor for GaN growth.

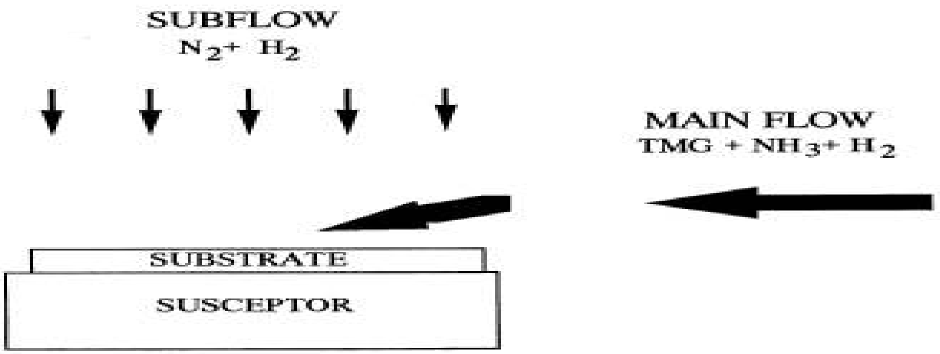


Fig. 2. Schematic principle figure of two-flow MOCVD.

"Novel Metalorganic Chemical Vapor Deposition System for GaN Growth"
S. Nakmaura et all, Appl. Phys. Lett. Vol 58, 2021 (1991)

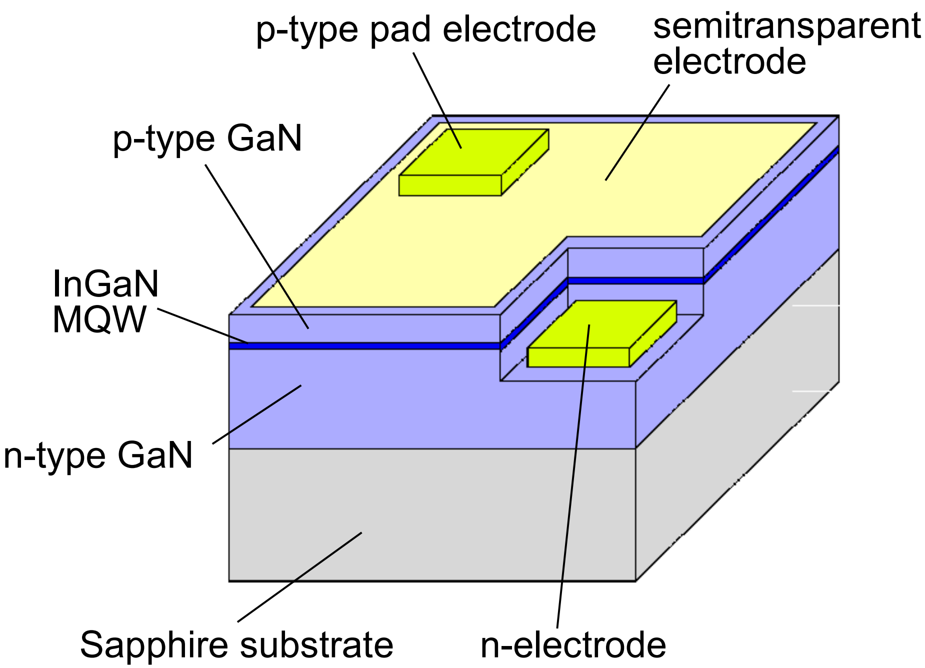
GaN or ZnSe for Blue LED in 1989

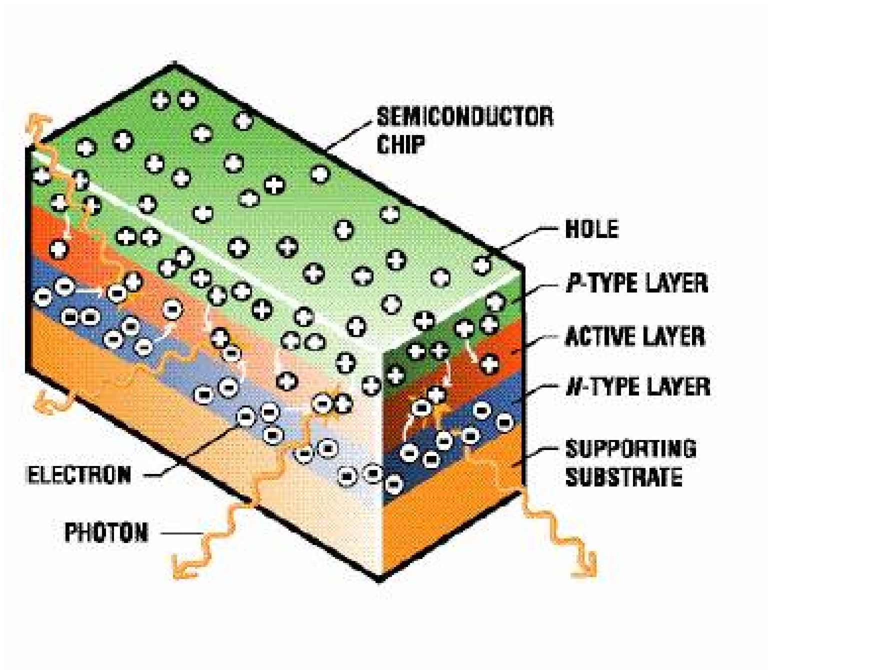
- ***ZnSe***
- High crystal quality: dislocation density is less than $1 \times 10^{3} cm^{-2}$
- Number of researchers: more than 10,000

- ***GaN***
- Poor crystal quality: dislocation density is more than $1 \times 10^{9} cm^{-2}$
- Number of researchers: around 10

- In 1989, I disparately selected GaN to write papers.
- I never thought that I could invent blue LEDs using GaN.
- Small company: small budget, one researcher

Typical Blue LED Structure on Sapphire

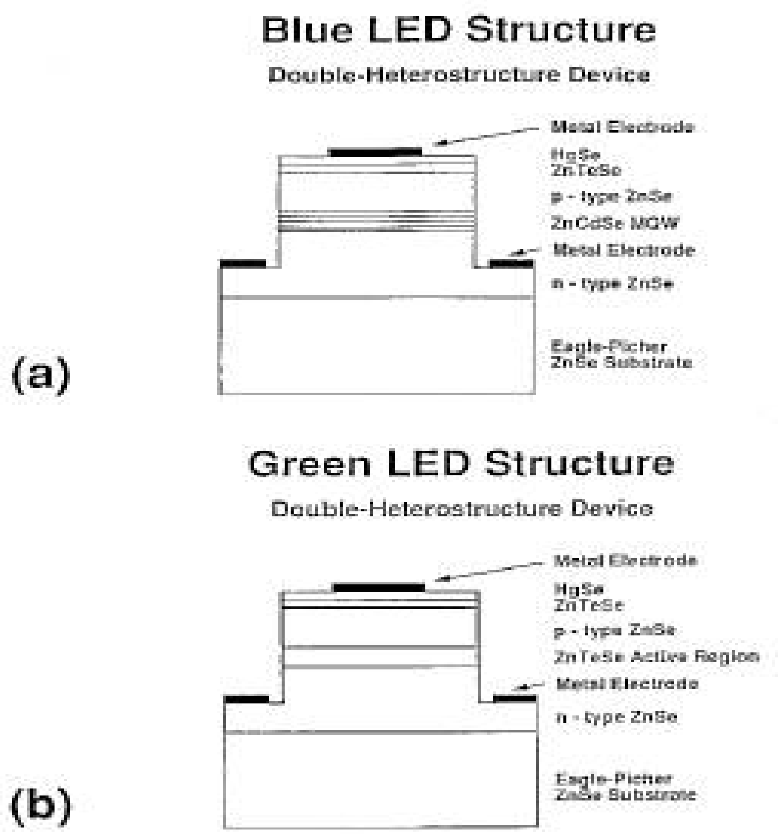


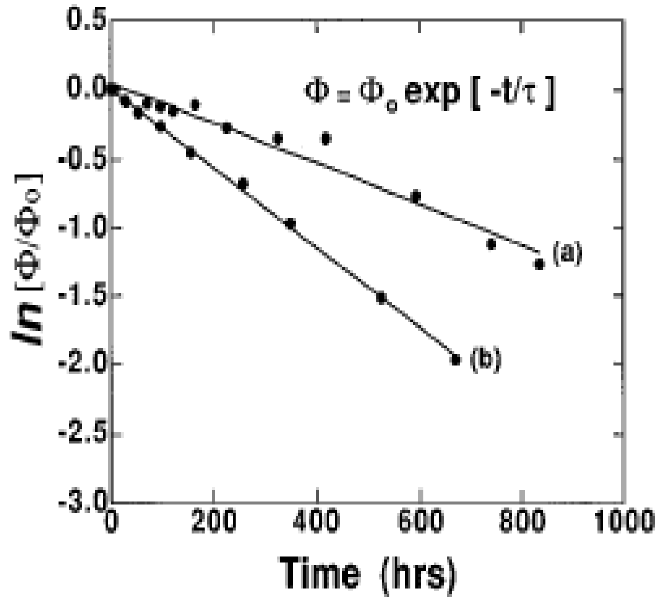


Blue LED produces light by combining positive and negative charges inside gallium nitride crystal

TEM image of InGaN MQW LD wafer

ZnSe-based LEDs in 1980-97

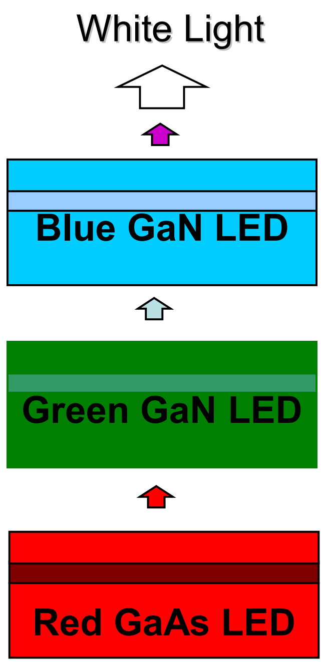


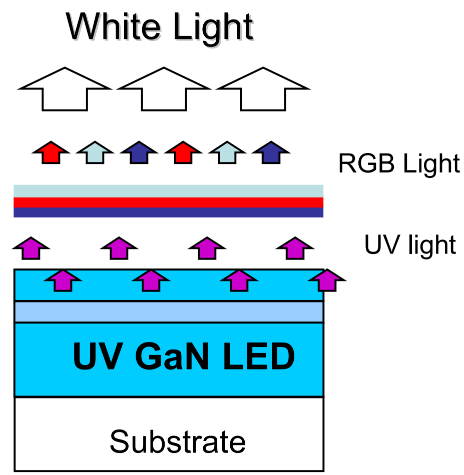


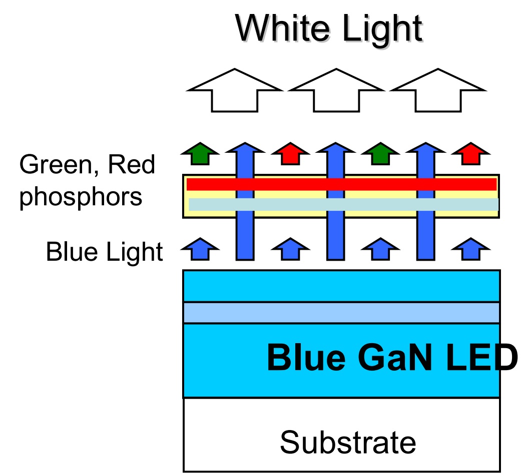
"High-brightness blue and green light-emitting diodes"
D.B. Eason et. all., Appl. Phys. Lett. Vol 66, 115 (1995)

3 Methods of Generating White LEDs

100 lm/W (2005)







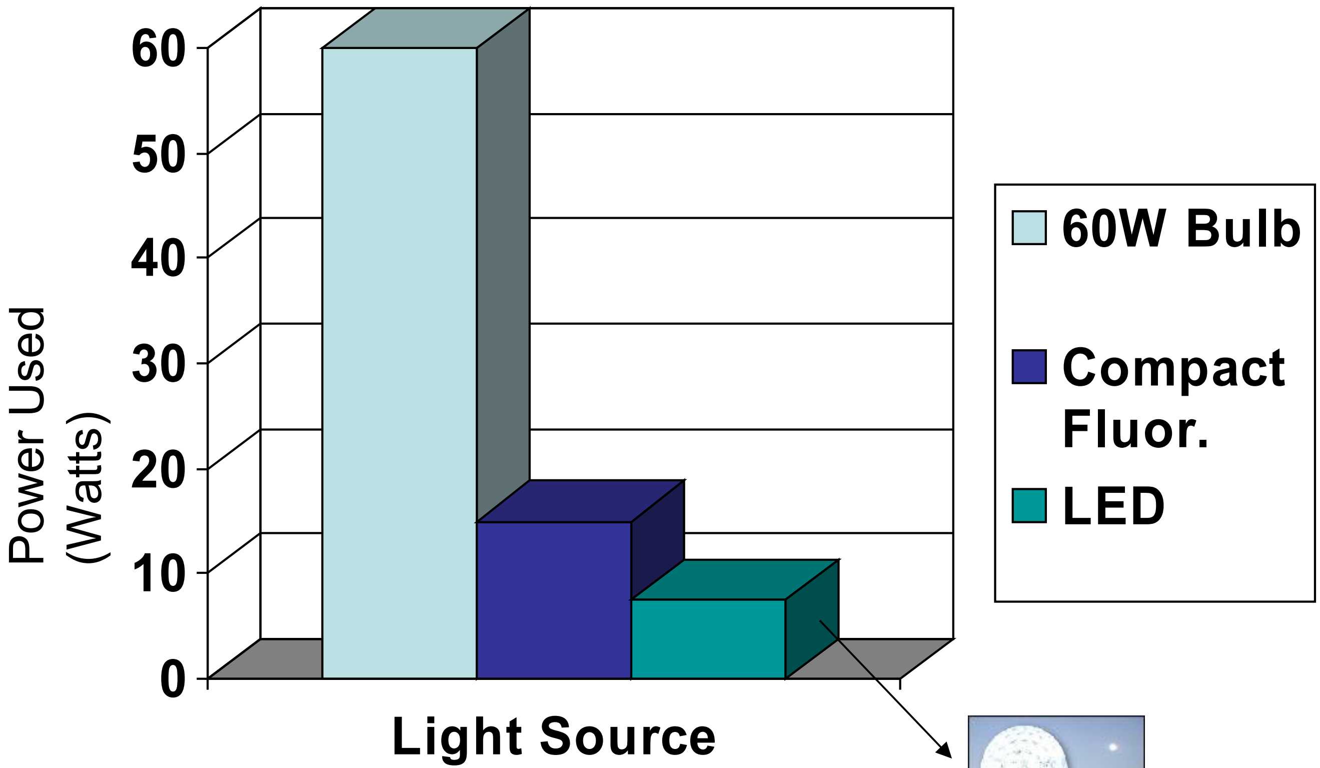
<u>Multi-Chip, RGB</u>
- good efficiency
- highest cost
- tunable color

<u>UV + Phosphors</u>
- best CRI,
- color uniformity
- low cost
- improve reliability

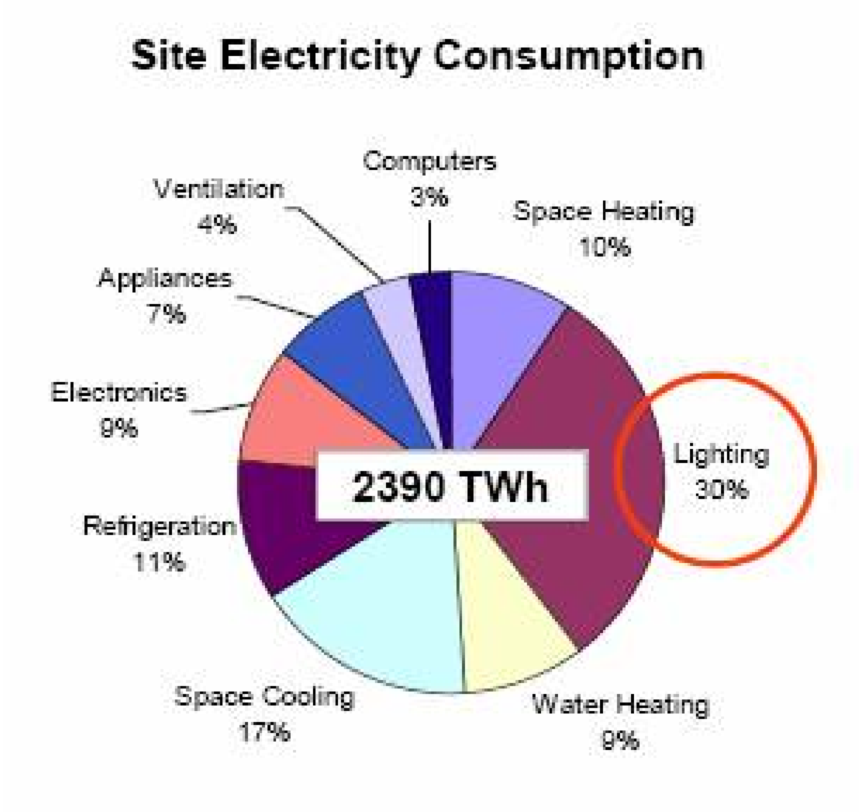
<u>Blue + Phosphors</u>
- lowest cost
- 100 lm/W
- 90% market share

"The Promise" Energy Usage Comparison

"Best" White LED and Compact Fluorescent vs. 60Watt Light Bulb Comparison



Lighting: Large Electricity Consumption



Lighting is single biggest user of electricity

- Incandescent Light Bulb -1-4% efficient
- Fluorescent – 15-25% efficient
- LED- 25-52% efficient (90% theoretical)

Outdoor

Light Up The World Foundation

www.lutw.org

- Kerosene lighting and firewood are used by 1/3 of the world; they cause countless fires and are very inefficient (0.03 lm/watt).
- The average villager spends 10-25% of their annual income on kerosene.
- LED Lighting costs much less on an annual basis and payback period is just 6 months.
- LED Lighting allows education at night and increases safety for the Third World.

"In the few months we have had the White LED lamps the improvement in the children's academic performance has been absolutely remarkable"

Headmaster, Mubarak Village, Pakistan June 2004

Global Warming/Energy Savings Potential of LEDs

If a 150 lm/Watt Solid State White source were developed, then in the United States alone:

- We would realize $115 Billion cum. Savings in 2025*
- Alleviate the need of 133 new power stations!*
- Eliminate 258 million metric tons of Carbon*
- Save 273TWh/year in energy**

*** "The Promise of Solid State Lighting" OIDA Report , 2001, http://www.netl.doe.gov/ssl/PDFs/oida_led-oled_rpt.pdf**
****A. D. Little, "Energy Savings Potential of SSL" Report for Dept. of Energy, http://www.eere.energy.gov/buildings/info/documents/pdfs/ssl_final_report3.pdf**

Air/Water Purification

- Fruit and Vegetable Storage Life Extended 1 week
- Water Purification: UV LED to kill bacteria

Mitsubishi Refrigerator MR-W55H, UV LED 375 nm, 590 nm, Blue LED

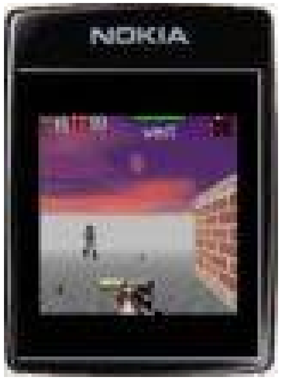
UV Water Purifier (Credit: Hydro-Photon Inc.)

- ***85 - 90 % Electricity Savings***
- ***5 + Year Life***
- ***Maintenance Savings***
- ***Tort Savings***

Philadelphia Replaced 14,000 Red Traffic Signals

Projected 5 Year Savings = $4.8 million

Current LED Applications



Cell Phone
(Nokia)

Traffic Signals
(Gelcore)

Large Displays
(NASDAQ)

Streetlights

TVs (LED DLP^{tm})
(Samsung)

Automotive

Future Concept Car from 2003 Tokyo Motor Show

Nissan

Honda

Daimlar Chrysler

Toyota

Display Case Lighting

American Fluorescent

GELcore

Portable Desk/Task Lighting

6 Watt LED Desk Lamp

Halley LED Desk Lamp

LEDs in Architectural Lighting

LED Installation Benjamin Franklin Bridge, PA, USA (Color Kinetics Inc.)

Lighting Systems by Color Kinetics Inc. (Takarazuka University of Art and Design)

Ultra-Mobile LED Enabled products

- Personal Pocket Projector

  Uses Blue, Green, Red LEDs

MITSUBISHI ELECTRIC
PRESENTATION PRODUCTS

- Cell Phone Camera Flash

(Osram Opto)

LED Plant Growth

- **Blue and Green LEDs used to grow Wasabi at night.**
- **Chlorophyll has a distinct absorption peak in the vicinity of 450nm (blue light region) and another at 660nm (red light region) in its light absorption spectrum.**
- **The blue light is also indispensable to the morphologically healthy growth plant. Red light also contributes to the plant photosynthesis.**

LEDs for Plant Growth in Space

- **Lettuce and LEDs: Shedding New Light On Space Farming, Reported by Todd Halvorson**

  Cape Canaveral Bureau Chief

  http://www.space.com/businesstechnology/technology/light_farming_010926.html

Air/Water Purification

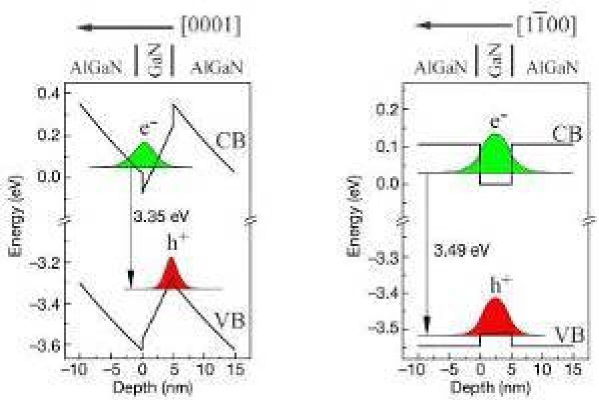
- Fruit and Vegetable Storage Life Extended 1 week
- Water Purification: UV LED to kill bacteria

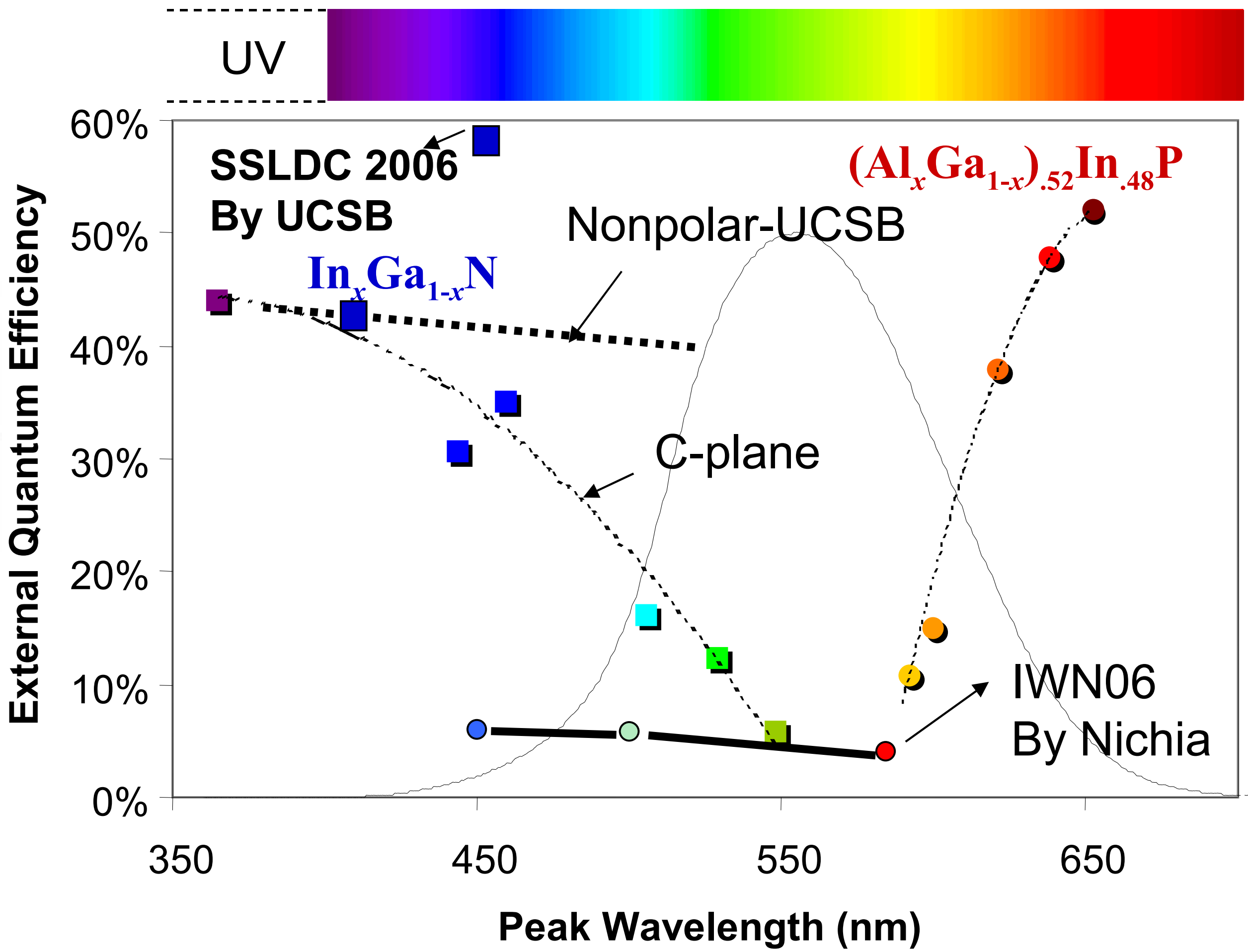
UV Water Purifier
(Credit: Hydro-Photon Inc.)

Mitsubishi Refrigerator MR-W55H,
UV LED 375 nm, 590 nm, Blue LED

Non-Polar GaN: LED Efficiency vs. Wavelength

- Polarization fields in polar QWs create problems in **green, ultraviolet, can Nonpolar solve the green gap?**





Laser TV

Mitsubishi "Laser TV" with Arasor and Novalux components (left) and Plasma (right)

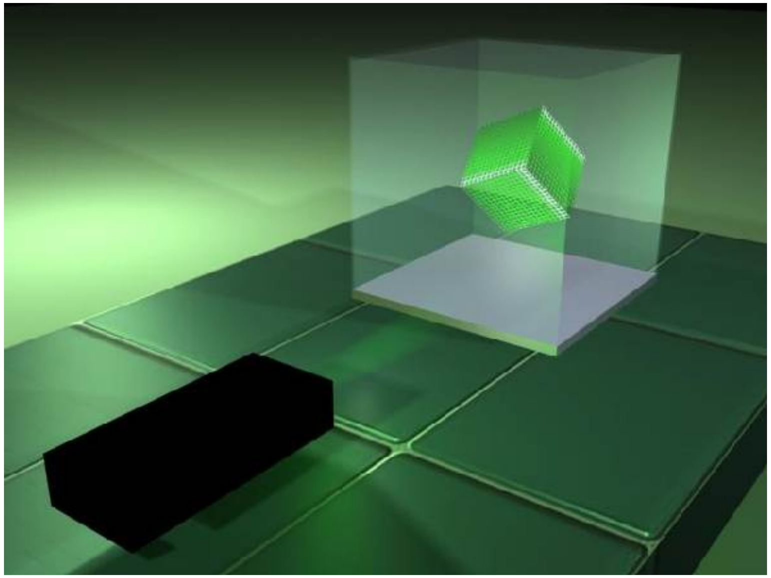
Future SSL Displays

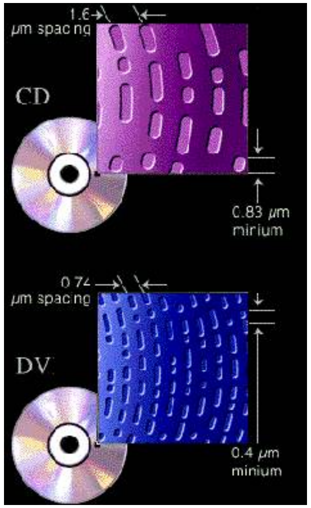
Pocket Projector/Cell Phone

Prototype from Novalux using frequency double lasers

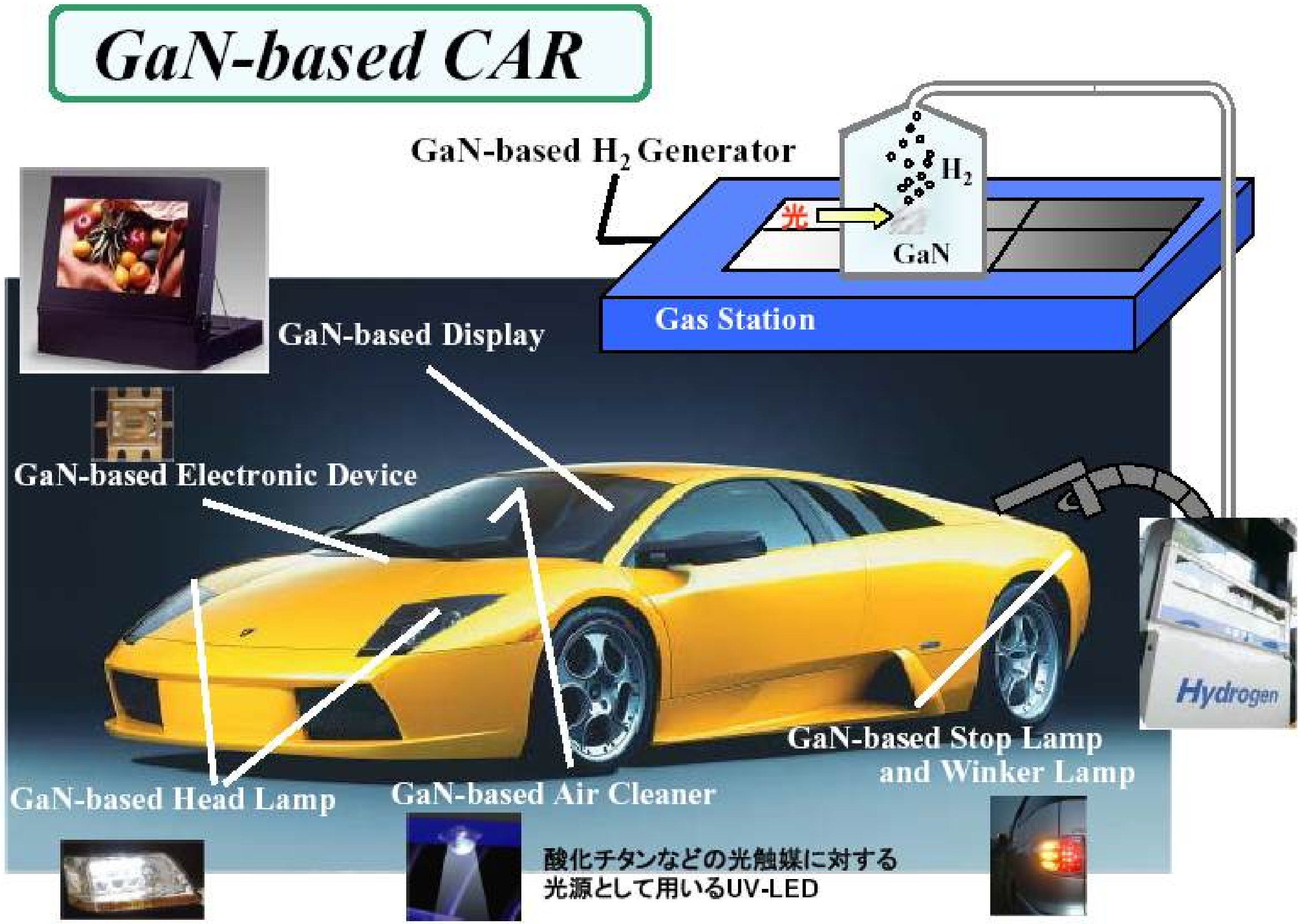
Applications for Blue, and Green Laser Diodes in Display

- Blue Laser for HD-DVD and Blu-Ray
- Blue and green for laser projection displays and holographic image





Future GaN Technology



UCSB SSLDC

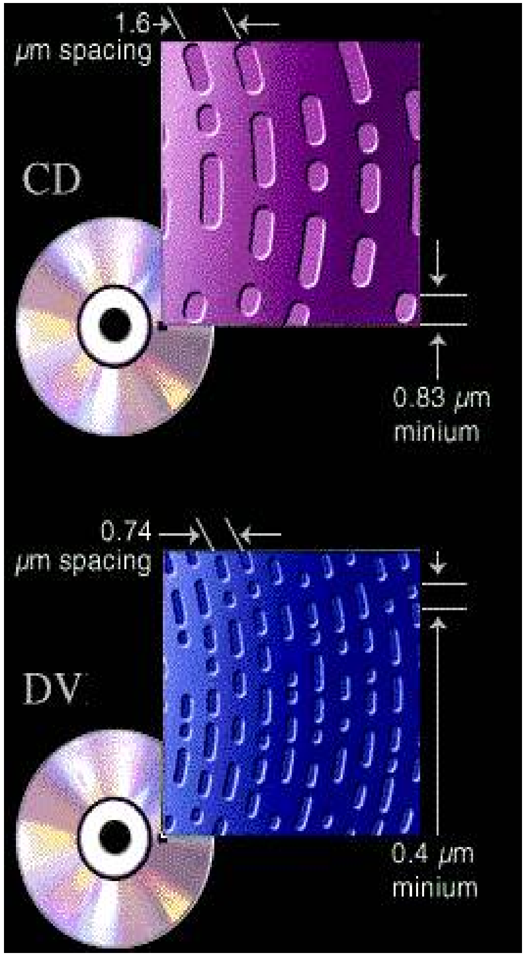
GaN Lasers enables Blu-Ray and HD-DVD

Blu-ray Disc

HD DVD

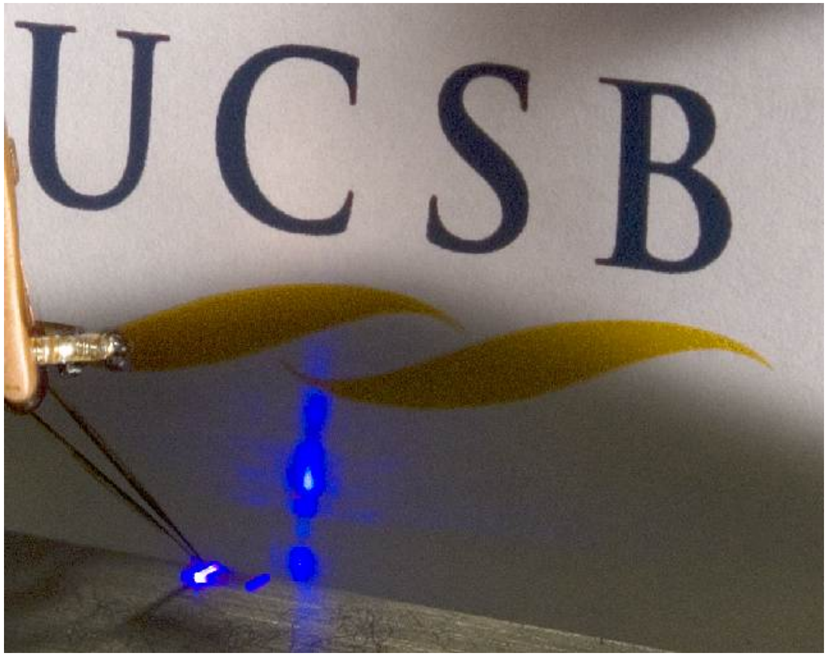
- Next generation large capacity optical disc video recording formats called "Blu-ray Disc“ and “HD-DVD” for recording, rewriting and play back of up to 27 gigabytes (GB) of data will use 405nm blue-violet laser diode.

HD-XA1



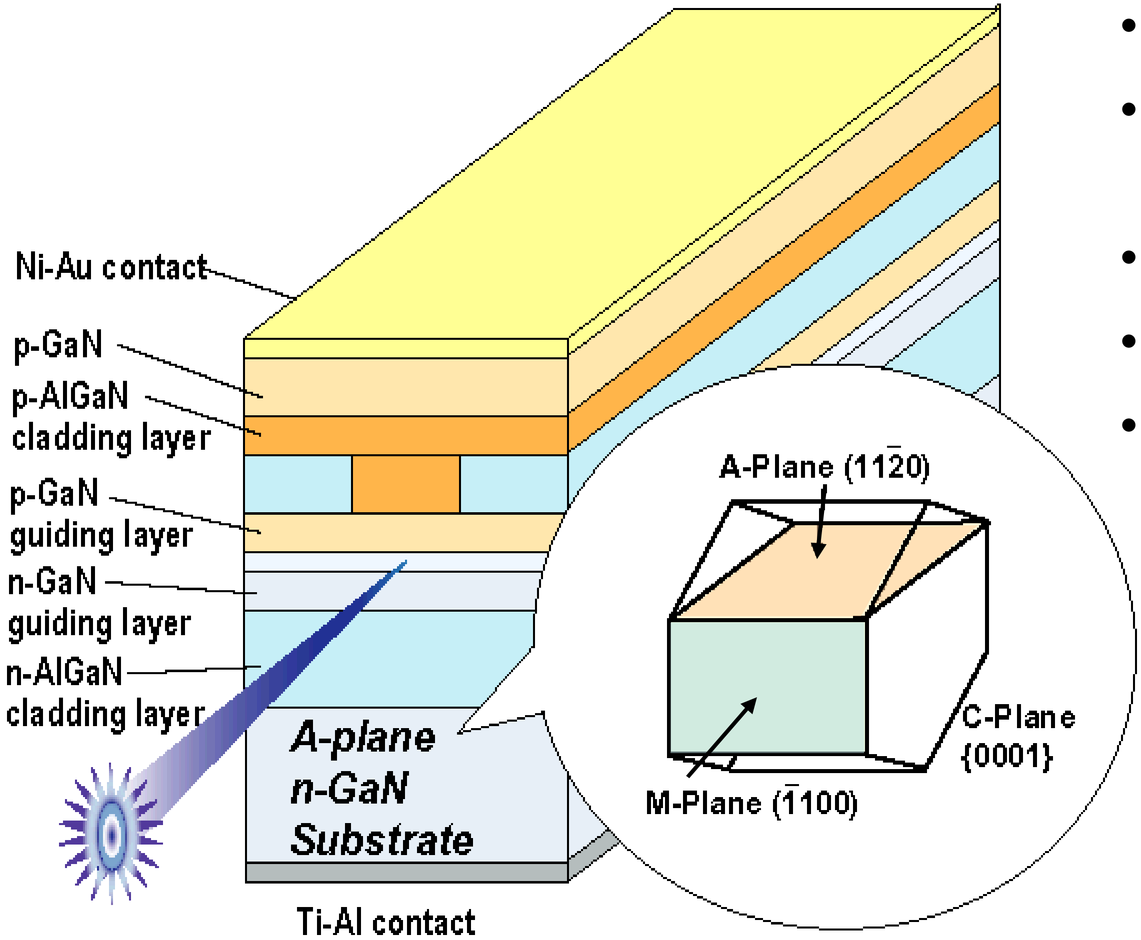
Blue Laser for High Density HD-DVD Optical Storage

Toshiba HD-DVD Player



UCSB Blue Laser Diode Chip

Nonpolar/Semipolar GaN Motivation for LDs



- Low dislocation density
- No polarization field-induced charge separation in QWs
- Lighter hole mass
- Low threshold current
- M-plane: cleaved mirror

Low threshold current, High reliability