JSPS Science Dialogue
Iwata Minami High School
Shizouka, Japan
27th Sep. 2007

Light emitting devices:
Fundamentals and Applications

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Contents

- India in Brief....
- Semiconductors
- Light Emitting Diode
- LASERs
- VCSELs
- Applications

Fundamentals & Examples
Part-I
A brief introduction to India
Where are we?

INDIA

JAPAN
(Nippon)

INDIA
(Bharat)
Humble Greetings

*NAMASTE*  
India

*Koninchiwa*  
Japan
2007 : India - Japan Friendship Year !!
Excellent Indo - Japan relations (Aug. 2007)

Dr. Manmohan Singh
Prime Minister-India

Mr. Shinzo Abe
Former Prime Minister-Japan
Largest democracy in the world
7th Largest country in the world
<table>
<thead>
<tr>
<th><strong>India in brief…</strong></th>
</tr>
</thead>
</table>
| **Population**      : 1.12 billion  
                      \(1,129,866,154 \text{ on July 2007}\) |
| **Capital**         : New Delhi |
| **Literacy**        : 61% (M-73.4% & F-47.8%) |
| **States & Union Territories** : 28 & 7 |
| **National Language** : Hindi & English |
| **Official Languages** : 22 |
| **Currency**        : Indian Rupee (INR) |
| **Life expectancy** : 68.59 (M-66.28 & F-71.17) |
Official languages of India (22)!!

Sanskrit Based

Dravidian
- Tamil, Telugu, Kannada, and Malayalam

Indo-Aryan
- Assamese, Bengali, Bodo, Dogri, Gujarati, Hindi, Kashmiri, Konkani, Maithili, Manipuri, Marathi, Nepali, Oriya, Punjabi, Rajasthani, Santali, Sindhi, and Urdu.

Diversity

Neighboring Nations
- Nepal, Nepali
- Urdu, Pakistan
- Bengali, Bangladesh
Multiple Religions (% of population)

India

- Hindu: 80.46%
- Muslim: 13.43%
- Christian: 2.34%
- Sikh: 1.87%
- Buddhist: 0.77%
- Jain: 0.41%
- Others: 0.65%

Population on July 2007: 1,129,866,154
My City - Rajahmundry with Godavari River
My home town: Dowlaiswaram

Sir Author Cotton Barrage for Irrigation of crops
Ancient Indian Mathematics
From 2600 BC to 18th century AD

Important contributions were made by scholars like
Aryabhata, Brahmagupta, and Bhaskara II.

Decimal number system 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9
Positive and negative numbers +6, -9 etc.
Arithmetic, Algebra, Trigonometry, Geometry, Calculus, etc.

\[
sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \cdots
\]

\[
\frac{1}{1 - x} = 1 + x + x^2 + x^3 + \ldots + \infty
\]

\[
\sqrt{2} = 1 + \frac{1}{3} + \frac{1}{3 \cdot 4} - \frac{1}{3 \cdot 4 \cdot 34} \approx 1.4142156\ldots
\]

\[
\pi = 3.14159265358979323846264338327950288419716939937510
\]
Lord Buddha originated from India (563 to 483 B.C)

- Statue of Buddha in Gupta’s period
- Original Bodhi Tree in Bodhgaya in Bihar, India
Takshila, **Nalanda university**
(First centers of higher learning in the world, 300 BC)

Nalanda was not a formal college or university. Instead there were renowned teachers who taught various subjects like *medicine, astronomy, astrology, Commerce, accountancy, law, magic, music, painting, crafts, archery* and the study of the Vedas. Students sought admission when they were about 16.
Taj Mahal (1632-1648)

Wonder of the world!!

Built by Emperor Shah Jahan for the memory of his wife Mumtaz Mahal

A symbol of love!!
Popular Arts

Kuchipudi, the traditional dance of Andhara pradesh

Bharatanatyam-Indian Classical Dance
Masako Ono
(Japanese National)
During Odyssey Show in India
Typical food of India

South Indian meals

North Indian meals
Historical Places

- Pink City - Jaipur
- Tirumala - Andhra Pradesh
- Kajuraho - MP
- Kutub Minar - Delhi
- India Gate - Delhi
- Gate way of India - Mumbai
- Charminar - Hyd
- Srinagar - Jammu & Kashmir
- Minakshi temple - Madurai
Nobel Prize Winners from India

RABINDRANATH TAGORE (1913-Literature)

CHANDRASHEKAR VENKATA RAMAN (1930-Physics)

HARGOBIND KHORANA (1968-Medicine)

SUBRAMANIAN CHANDRASHEKAR (1983-Physics)

MOTHER TERESA (1979-Peace)

AMARTYA SEN (1998-Economics)

V. S. NEILPAUL (2001-Literature)
Higher Education (Engineering & Technology)

Brand
IIT

IITs – 1 out of 200 applicants gets admitted !!

• IIT-Bombay
• IIT-Delhi
• IIT-Guwahati
• IIT-Kanpur
• IIT-Kharagpur
• IIT-Madras
• IIT-Roorkee

IIT = MIT + Harvard + Princeton

BBC
Over 1.12 billion population

28 states, 7 union territories

22 official languages

Multiple religions co-exist

1 Country

"Satyameva Jayate" (Sanskrit)
(Devanagari)

"Truth Alone Triumphs"
Part-II
Light Emitting Devices
**Fundamental Subatomic Particles**

<table>
<thead>
<tr>
<th>Particle</th>
<th>Symbol</th>
<th>Charge</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>electron</td>
<td>e^-</td>
<td>-1</td>
<td>0.0005486 amu</td>
</tr>
<tr>
<td>proton</td>
<td>p^+</td>
<td>+1</td>
<td>1.007276 amu</td>
</tr>
<tr>
<td>neutron</td>
<td>n^-</td>
<td>0</td>
<td>1.008665 amu</td>
</tr>
</tbody>
</table>
Carbon atom as an example

\[ C_{6}^{12} \quad 1s^2 \ 2s^2 \ 2p_x^1 \ 2p_y^1 \]

Valence electrons

Core electrons
Bohr’s Postulates

Electrons can change orbits by radiating (larger to smaller), absorbing radiation (smaller to larger) or by collisions (either larger to smaller or smaller to larger).

http://en.wikipedia.org/wiki/Niels_Bohr
Elements and Periodic Table

www.stanford.edu/class/educ299x/assignment1.html
Different states of matter

**Gas**
- atoms can move past one another

**Liquid**
- atoms can move/slide past one another

**Solid**
- atoms locked into place

---

http://www.chem.purdue.edu/gchelp/liquids/character.html
Electronic band structure in solids

Energy levels

one atom  two atoms  three atoms  many atoms

Energy bands

allowed  forbidden  allowed  forbidden  allowed
The concept of electron and hole in materials science involves the following:

1. **Conduction Band**
   - Represents the energy level where electrons are readily available for conduction.
   - Typically at the top of the valence band.

2. **Valence Band**
   - Represents the Energy level immediately below the conduction band.
   - Represents the filled energy levels that electrons occupy at absolute zero.

**Creation of Holes**

- When an electron in the valence band gains enough energy to跃过 the energy gap $E_g$ and move to the conduction band, it leaves a hole behind in the valence band.

**Hole**

- Is defined as the deficiency or absence of an electron in the valence band.

The diagram illustrates the process of creating holes through the transition of electrons from the valence band to the conduction band.
Motion of electron and hole

- Direction of bubble flow
- Direction of fluid flow
- Fluid/electrons
- Air bubble/holes

Water drop
Air bubble
Different types of semiconductors

- Intrinsic
- P-type
- N-type
- degenerate

- Elemental
- Binary
- Ternary
- Quartenary

Si, Ge
GaAs, InP
AlGaAs
InGaAsP

Doping

The addition of a small percentage of foreign atoms in the regular crystal lattice of intrinsic semiconductors produces dramatic changes in their electrical properties, producing n-type and p-type semiconductors.
Typical Semiconductors

**Silicon**
Bonding: covalent

**GaAs**
Bonding: covalent, partially ionic
Intrinsic (Un-doped) Semiconductor

Both electrons and holes contribute to current flow in an intrinsic semiconductor.

No of electrons = No of holes $\Rightarrow$ No net electric current !!

http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html
Extrinsic (doped) semiconductors

Si: $1s^2 2s^2 2p^6 3s^2 3p^2$
Sn: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^3$
B: $1s^2 2s^2 2p^1$

n-Type

p-Type

http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html
P-N Junction (Diode)

Forward bias - offers low resistance
Reverse bias - offers high resistance

http://www.mtmi.vu.lt/pfk/funkc_dariniai/diod/index.html
The Electromagnetic Spectrum

<table>
<thead>
<tr>
<th>gamma rays</th>
<th>X-rays</th>
<th>ultraviolet rays</th>
<th>infrared rays</th>
<th>radar</th>
<th>FM</th>
<th>TV</th>
<th>shortwave</th>
<th>AM</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{-14}$</td>
<td>$10^{-12}$</td>
<td>$10^{-10}$</td>
<td>$10^{-8}$</td>
<td>$10^{-6}$</td>
<td>$10^{-4}$</td>
<td>$10^{-2}$</td>
<td>1</td>
<td>$10^2$</td>
</tr>
</tbody>
</table>

Visible Light

Wavelength (nanometers)

Wavelength (meters)

http://links.baruch.sc.edu/scael/personals/pjpblecture/spectrum.gif
What is light?

Light = Photon (γ) = electromagnetic Wave

Wavelength = Distance between crests
Amplitude = Half height of trough to crest
Frequency = No of crests passing though a point in space every second

\[ E = h \frac{c}{\lambda} \]
\[ \lambda = \frac{c}{\nu} \]

- \( E \) = Energy (eV)
- \( C \) = Speed of light (3x10^8 m/s)
- \( \nu \) = Frequency (Hz)
- \( \lambda \) = Wavelength (µm)
- \( h \) = Planck’s constant
Interaction of optical processes with electronic processes

Optical processes
- Absorption
- Emission
- Reflection
- Transmission

Electronic/electrical
- Current
- Voltage
- Power
- Resistance

\[ e^- + h \rightarrow hv \]

⇒ Interaction of photons with electrons and holes
Optical processes in semiconductor atoms

$\hbar \nu > E_c - E_v$

$e^- - h$ annihilated and appears as emitted light

- **LED**
- **LASER**

Spontaneous absorption (a)
Spontaneous emission (b)
Stimulated emission (c)
Light emitting devices (Light sources)

At all possible wavelengths in EM spectrum

**LED**
- **Spontaneous emission**

**LASER**
- **Stimulated emission**

**LED** - Light Emitting Diode
**LASER** - Light Amplification by Stimulated Emission of Radiation
Light Emitting Diodes (LEDs)

Electroluminescence

electron-hole pair drops into a more stable bound state, emitting energy in the form of a photons.

Forward Biased p-n junction

In-coherent Emission

Color Displays

Source: Encyclopedia RP-Photonics
1921 Albert Einstein first theoretically proposed the Idea
1961 First experimental demonstration of Ruby-LASER

**Light Amplification of Stimulated Emission of Radiation (LASER)**

**Major Characteristics of LASER**

- Monochromatic (Single wavelength)
- Coherent (All photos have same phase)
- Collimated (Parallel output beam)
Structure of LASER

1. Source  
2. Gain Medium  
3 and 4 Reflectors  
5. Output

Pump + Gain medium + Resonator
Ruby-LASER

1960, Dr. Maiman (USA) $\lambda = 694.3$ nm

Hughes Research Laboratories

First invention of LASER in the world 1960

Theodore Harold Maiman
Different types of lasers

- Gas LASERs
- Chemical LASERs
- Solid State LASERs
  - Fiber LASERs
  - Semiconductor LASERs
- Dye LASERs
- Free electron lasers
He-Ne Gas Laser for barcode reader

1960, Ali Javan, William Bennet Jr. and Donald Herriot, $\lambda = 632.8$ nm, Bell Labs, USA

Nd:YAG Solid state Laser

1964, Geusic et al. $\lambda = 1064$ nm, Bell Laboratories, USA

Eye cataract surgery, laser hair removal, manufacturing for cutting and welding steel, Dentistry and so on...

1960, Ali Javan, William Bennet Jr. and Donald Herriot, $\lambda = 632.8$ nm, Bell Labs, USA
Fiber LASER

The Gain medium of the fiber is doped with rare-earth ions $\text{Er}^{3+}, \text{Nd}^{3+}, \text{Yb}^{3+}, \text{Tm}^{3+}, \text{Pr}^{3+}$

Corning Inc. : Low loss optical fiber (1970)

Dye (Liquid) Laser


The wide bandwidth makes them particularly suitable for tunable lasers and pulsed lasers.

http://www.alspi.com/laser.htm
Organic/chemical laser

Cheap and tunable with optical pumping

350 nm-thick layer of spiro material on top of a silicon substrate with a series of etched parallel grooves (a grating).

Free electron laser

FELs use a relativistic electron beam as the lasing medium, hence the term free electron. This gives them the widest frequency range of any laser type, and makes many of them widely tunable, currently ranging in wavelength from microwaves, through terahertz radiation and infrared, to the visible spectrum, to ultraviolet, to soft X-rays.

Advanced Materials 17 31 2005
Semiconductor laser (or) Laser Diode

The most commonly used laser today !!

1962
4 different groups simultaneously reported !!

In their simplest form it consists of a small rectangular slab of semiconductor material with two cleaved facets to act as mirrors.

Injection laser diodes

A forward biased p-n junction powered by injected electrical current.

Edge emitting lasers
1962-1977-after

- Double heterostructure lasers
- Separate confinement lasers
- Distributed feedback lasers
- Quantum well lasers
- Quantum dot lasers
- Quantum wire lasers

Innovative Research and Development over 3 decades

Edge emitting OR In-plane lasers
Invention of Surface Emitting Lasers

VCSEL Idea

1977 by K. Iga

Prof. Emeritus, Kenichi Iga, 1977
Tokyo Institute of Technology

Celebrating 30th anniversary of VCSELs!

F. Koyama, iNOW-2007, Beijing & Lanzhou, China
Comparison between edge emitting VS surface emitting lasers

Few important parameters

Edge emitting lasers

Surface emitting lasers

Active layer volume

$60 \mu m^3$

$0.06 \mu m^3$

Cavity Length

$300 \mu m$

$\approx 1 \mu m$

Threshold current

$\geq mA$

$< \mu A$

$1 \mu m = 10^{-4} \text{ cm} = 1000 \text{ nm}$

Short-Cavity and Low power consumption causes high performance !!

Why surface emitting lasers

Vertical Integration?
Principle of VCSEL

P. L. Gourley
Nature 371 (1994) 571
Why VCSELs ???

Low power consumption
Small footprint
2D array integration
Wavelength tuning
Wafer level testing

→

High speed LAN
Optical interconnect
Optical signal processing
Optical sensing
High power applications

Surface emitting laser array

F. Koyama, iNOW-2007, Beijing & Lanzhou, China
Applications of VCSELs

VCSEL Photonics

Datacom

Sensing

Display

Printing

Interconnects

after Novalux

after Logitech

after FujiXerox

after IBM/Agilent

F. Koyama, iNOW-2007, Beijing & Lanzhou, China
Optical Interconnections

Features
Free from EMI
High speed > 1Gbps
Low power consumption
Small footprint

F. Koyama, iNOW-2007, Beijing & Lanzhou, China
VCSEL Array
Low Power Consumption
Small Footprint

Target:
- 100Gbps Parallel Link Modules
- 850nm & 1300nm wavelength bands
- Multi-wavelength Array beyond 100Gbps

F. Koyama, iNOW-2007, Beijing & Lanzhou, China
International Symposium on Optical Communications
New Green pia Hotel, Tsunan, Niigata, Japan
6th-8th August, 2006

From Left
My self
Prof. K. Iga
Prof. Y. Suematsu
Prof. F. Koyama
Part-III
Leadership and Management
Leadership Vs Management

**Leader**
- Do Right Things
- Coping with Change
- Architects
- Ask why and what?
- Innovative
- Relay on trust
- Long-Range Views

**Manager**
- Do Things Right
- Coping with Complexity
- Builders
- Ask How and When?
- Administrative
- Relay on Control
- Short-Range Views

Leadership is action, not position.
Donald H. McGannon
Marks of a Great Leader

- Courage and confidence
- Servicing and sacrificing
- Initiating and risk taking
- Needing no credit
- Empowering others
- Clarifying values
Marks of a Great Leader

- Honest, trustworthy
- Good role model
- Caring
- Committed

- Good listener
- Respectful
- Positive, enthusiastic
- Passionate

Are we born with these qualities or are they learned behaviors?

To some degree we have all of them!! We must practice these qualities in ourselves if we are to be effective leaders.
The poor man is not he who is without a cent, but he who without a dream.  

Harry Kemp
Conclusions

• India in-brief : Unity in Diversity in the world !!

• Light emitting devices
  • LED
  • LASER
  • Semiconductor LASER
  • VCSEL & Optical Communication Applications

• Leadership !!
Acknowledgements

• JSPS, Science Dialogue staff
• Iwata Minami High School SD Organizers
• Prof. Kenichi Iga (JSPS)
• Prof. Fumio Koyama, (Tokyo Tech.)
• Mr. Satoshi Suda, (Tokyo Tech)
• All of you !!