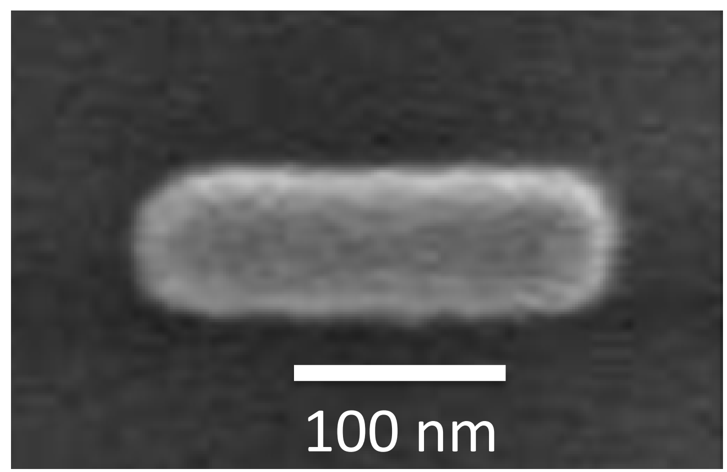
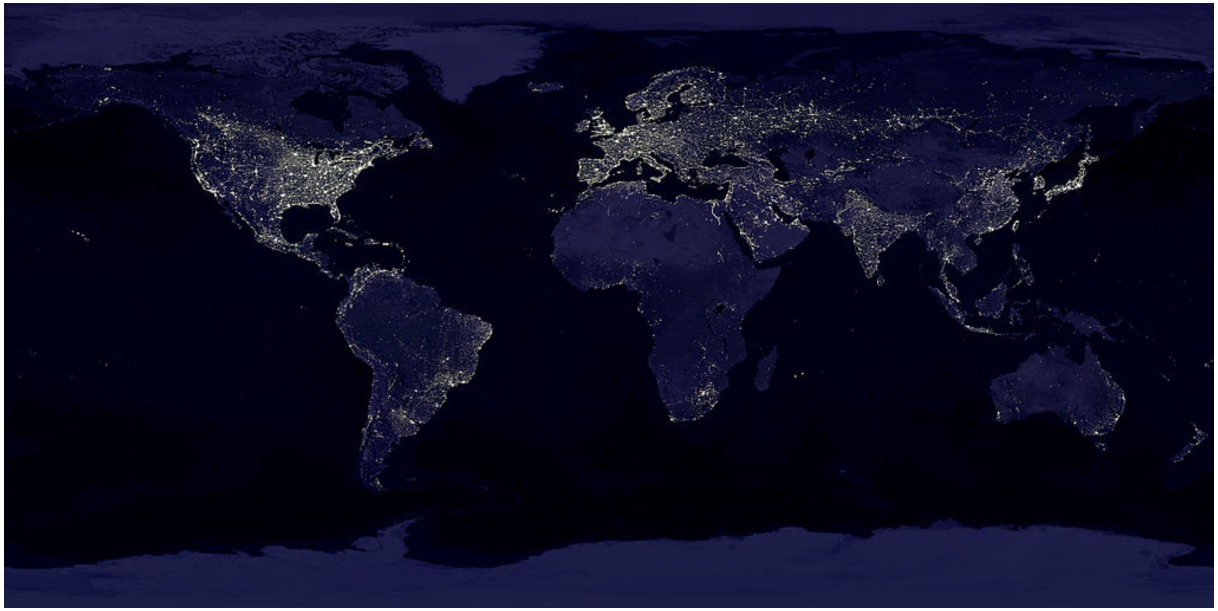
DIFFER TU/e FOM Institute AMOLF PHILIPS

Bringing nanotechnology into LEDs

Jaime Gomez Rivas

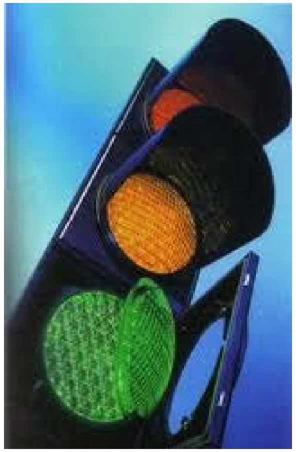


Lighting



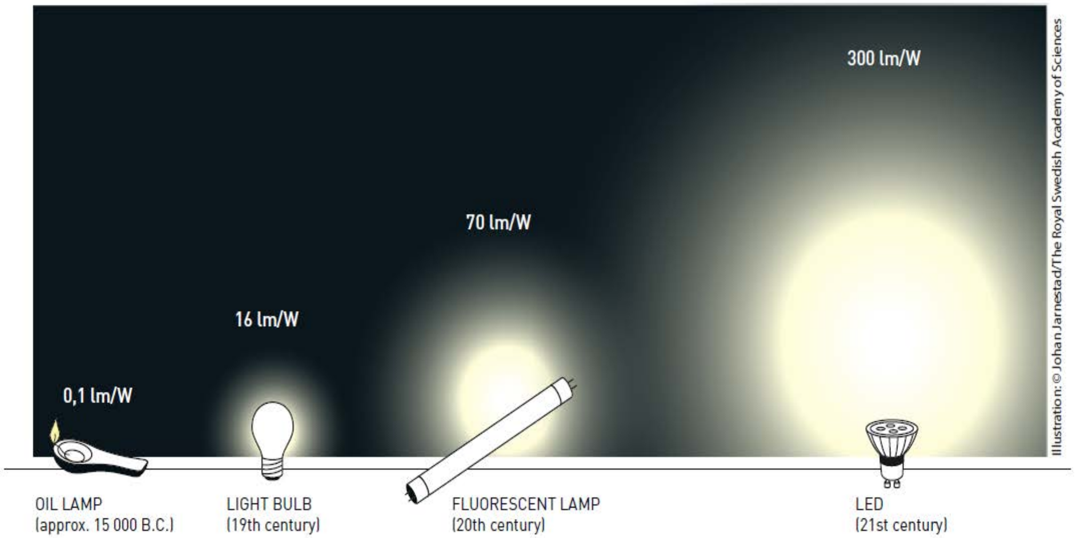
Electricity for lighting accounts for approximately **15%** of global power consumption

The LED/solid state lighting revolution



Impact of solid state lighting

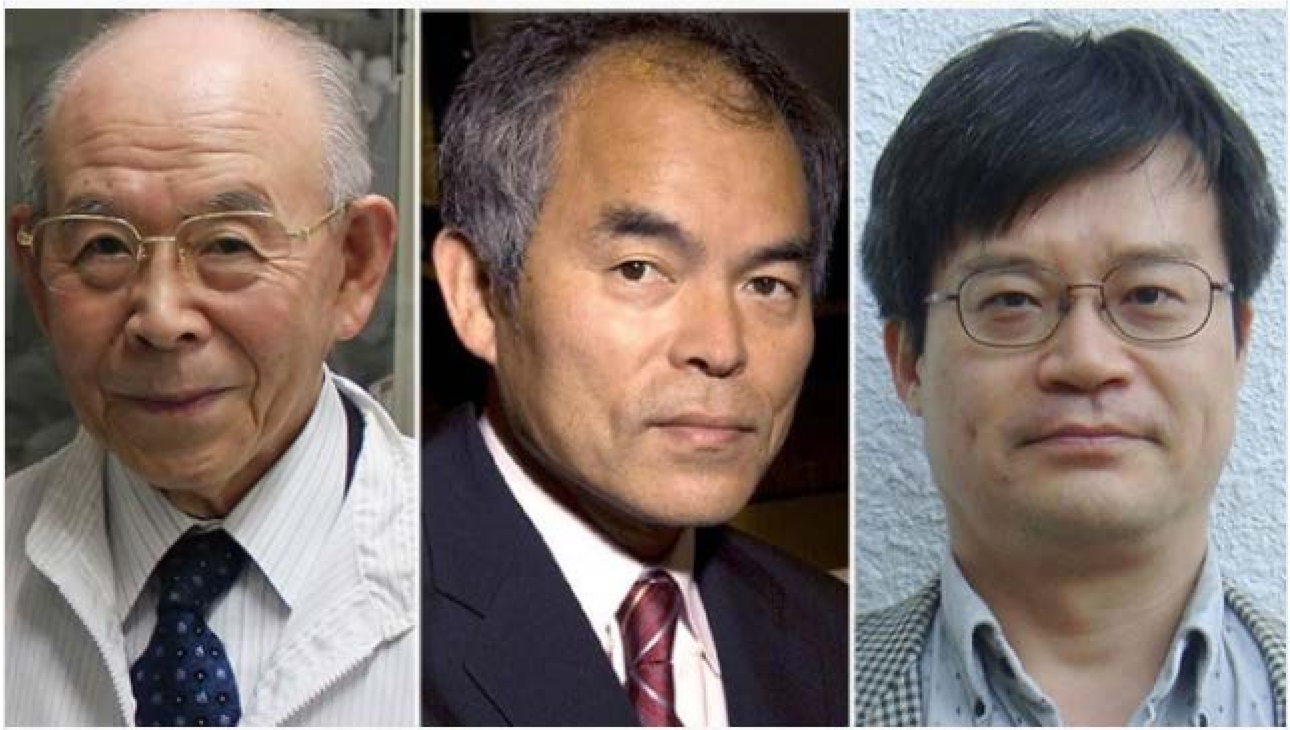
- LEDs are 20 times more efficient than incandescent lamps.
- LEDs enable electrical artificial lighting off the grid (devolping countries)
- LEDs have a usable life time 100 times longer than incadescent lamps and 10 times longer than fluorescent lights.



*Press release of The Royal Swedish Academy of Science (7 October 2014)

The Nobel Prize of Physics 2014

Isamu Akasaki　　Shuji Nakamura　　Hiroshi Amano

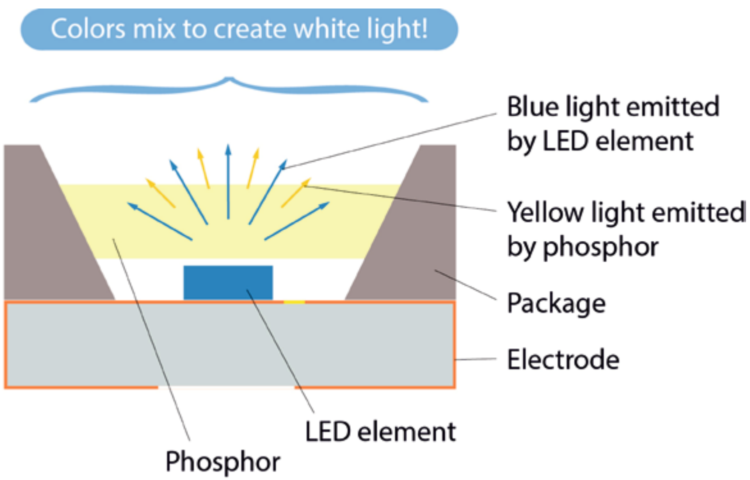


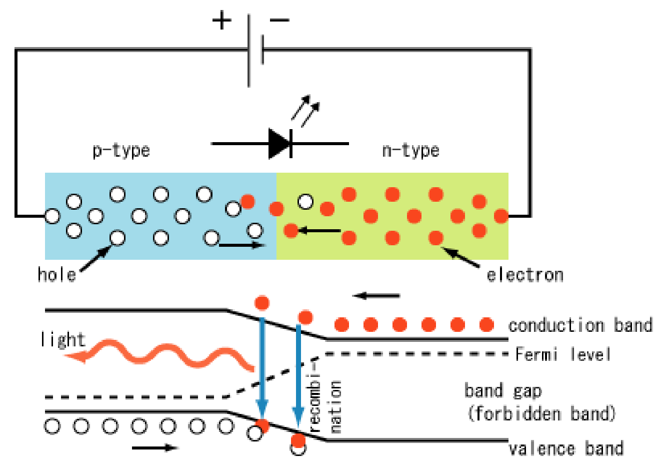
1929-Meijo Univ.(Nagoya Univ.)　1954-UCSB (Nichia)　1960-Nagoya Univ. (Nagoya Univ.)

The Nobel Prize in Physics 2014 was awarded jointly to Isamu Akasaki, Hiroshi Amano and Shuji Nakamura *"for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources".*

White light solid state lighting

Phosphor-converted white LEDs





Two conditions:

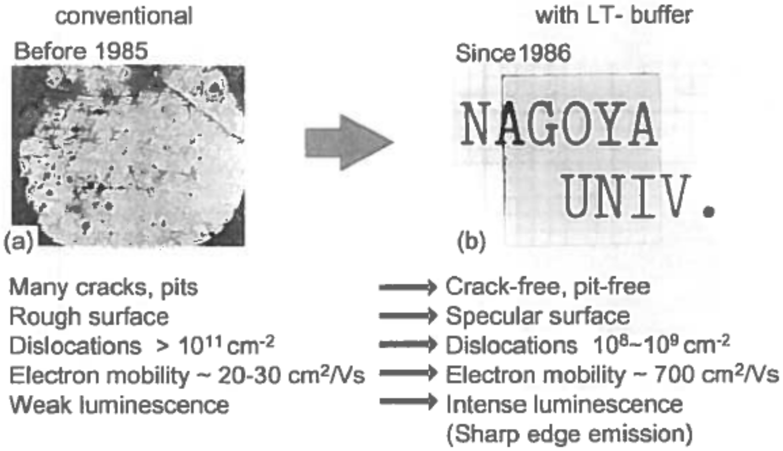
- Semiconductor with the right energy band gap
- Efficient radiative recombination.

p-n junction, crystal quality, heterostructures and quantum wells

History

- 1973 – Akasaki "I decided to make the realization of blue light emitting devices by GaN p-n junctions, an idea abandoned by many, my life's work"

Amano PhD student of Akasaki from 1985 to 1989

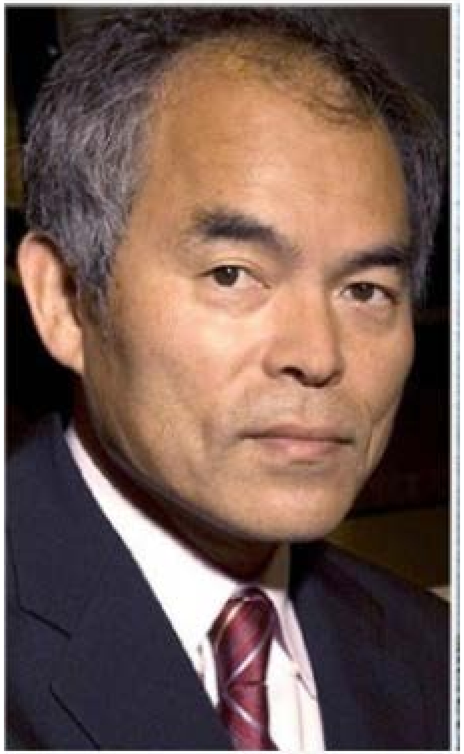


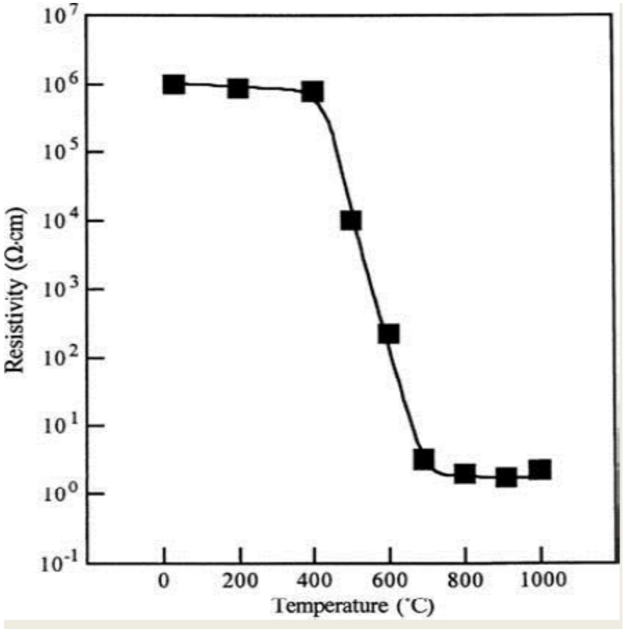
Two challenges:

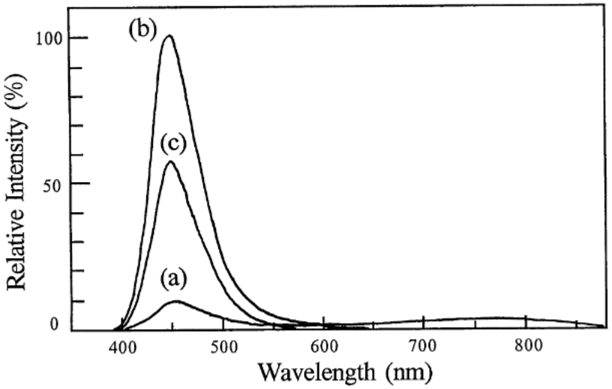
- Quality of the material
- p-doping

History

Nakamura clarified the annealing process (hydrogen passivation of acceptors). Thermal treatment of the GaN in a N_2 atmosphere for the activation of p-dopands (Jap. J. Appl. Phys 1992)



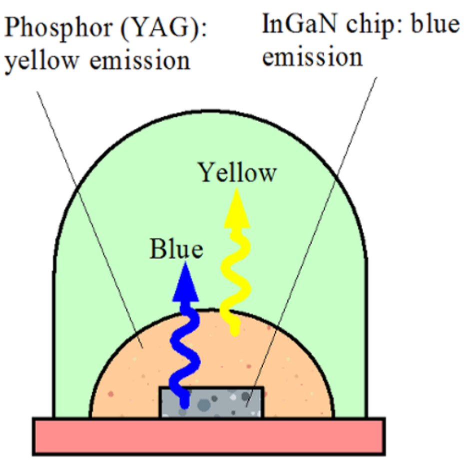




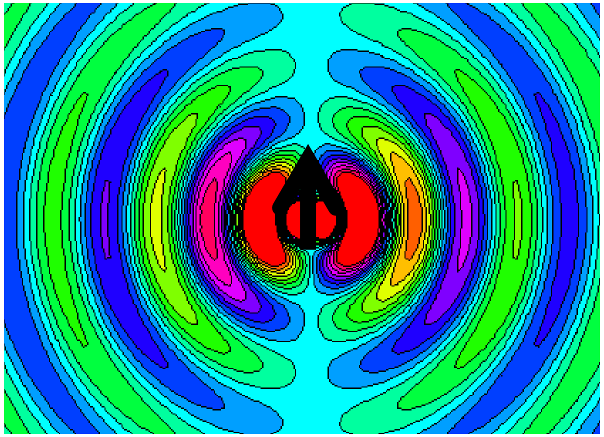
S. Nakamura, T. Mukai, M. Senoh and N. Iwasa, *Jpn. J. Appl. Phys.* ***31, L139 (1992).***

Our work

Full control on the emission characteristics of optical sources for solid state lighting applications (LEDs): Improve efficiency, reduce material and increase funtionality, e.g., beaming.

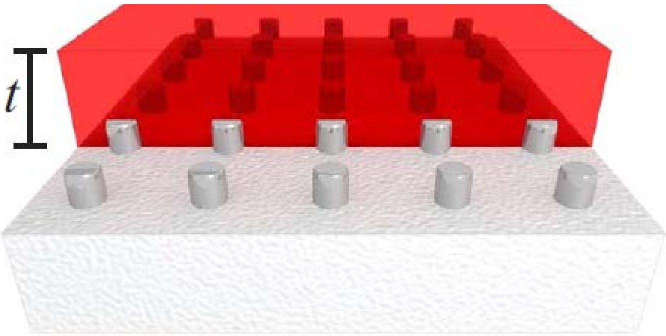


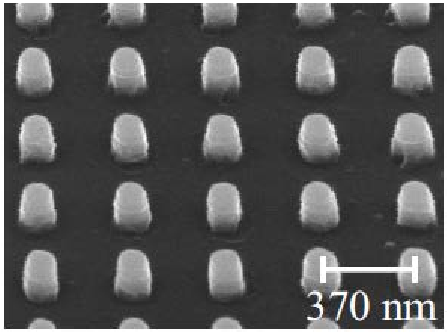
White LED



Dipole : Highly localized source of electromagnetic radiation $\rightarrow$ Highly non-directional source

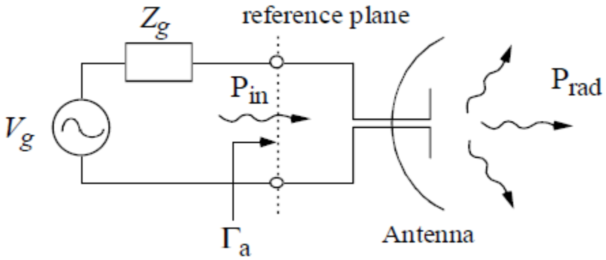
$$\delta\vec{r}\,\delta\vec{p} \geq \hbar / 2$$





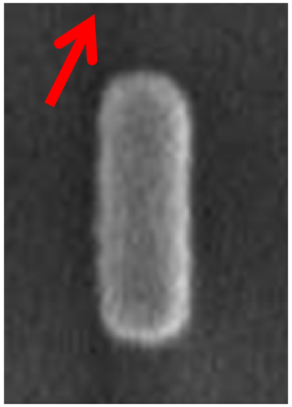
Antenna: definition

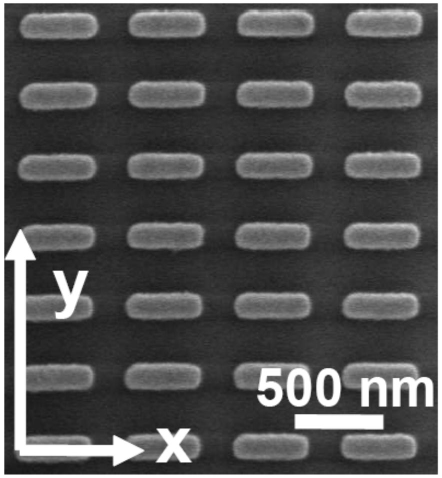
An antenna is a device which converts the energy of free propagating radiation to localized energy, and vice versa

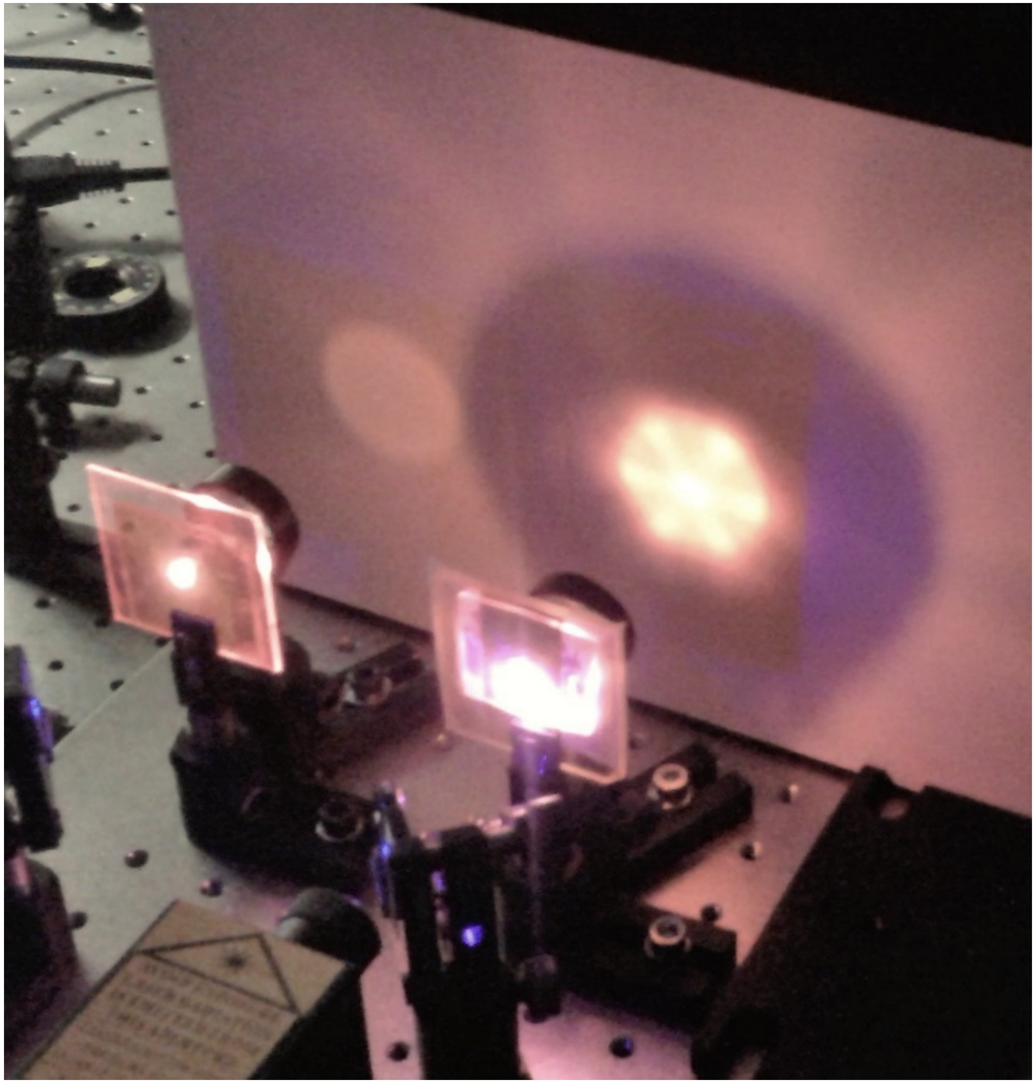


RF antennas

Plasmonic antennas





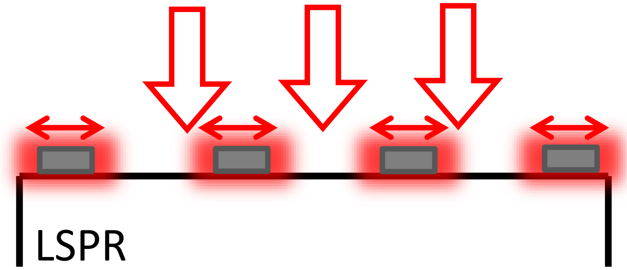


Plenty of Room at the Bottom (Feynman, 1959)

Consider, for example, a piece of material in which we make little coils and condensers (or their solid state analogs) 1,000 or 10,000 angstroms in a circuit, one right next to the other, over a large area, with little antennas sticking out at the other end—a whole series of circuits. Is it possible, for example, to emit light from a whole set of antennas, like we emit radio waves from an organized set of antennas to beam the radio programs to Europe? The same thing would be to beam the light out in a definite direction with very high intensity. (Perhaps such a beam is not very useful technically or economically.)

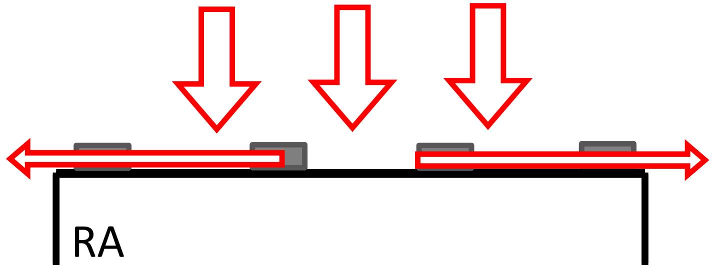
Collective plasmonic resonances

Localized surface plasmon polaritons

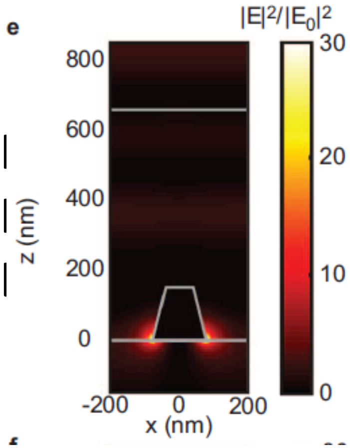


- Plasmonic mode
- High local fields
- Metal losses

Rayleigh anomalies



- Photonic mode
- Weakly confined



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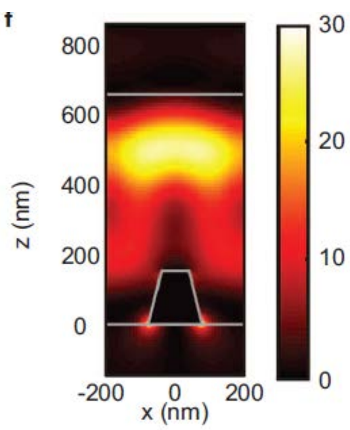
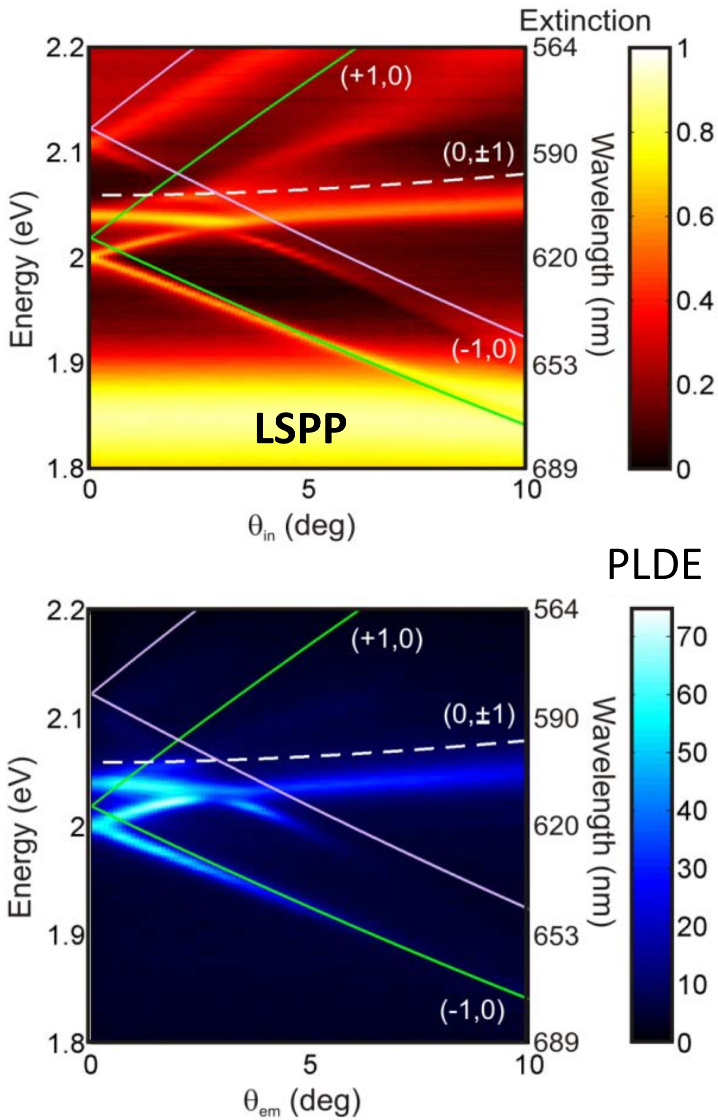
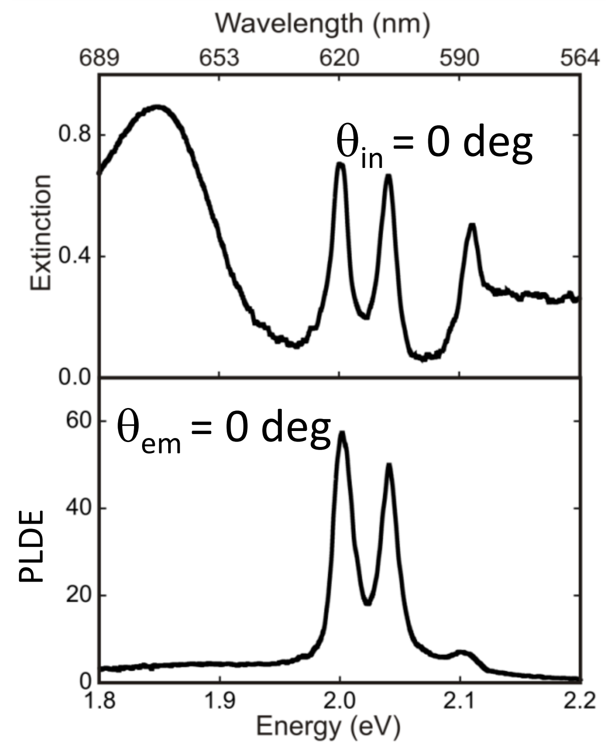


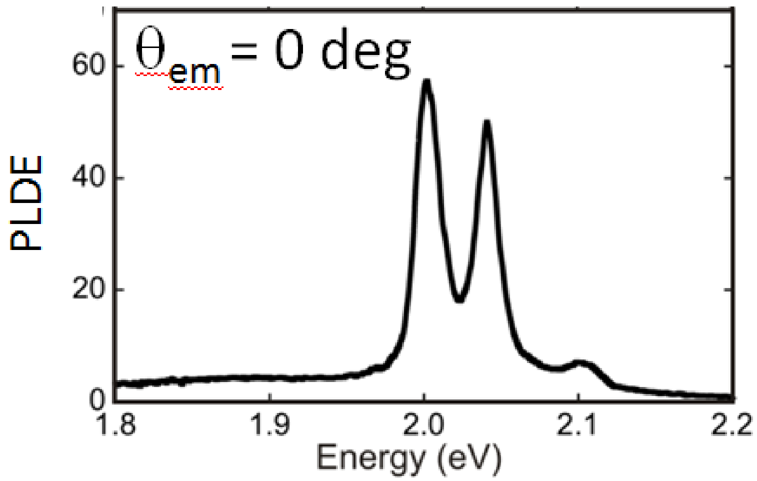
Extinction and PL enhancement

Aluminum nanoparticle array + dye-doped polymer (~85% IQE)





PL directional enhancement



Quantum efficiency

Directivity

Absorption

$$\mathrm{PLDE} = \boxed{\frac{\eta(\omega_{em})}{\eta_{ref}(\omega_{em})}} \boxed{\frac{D(\theta_{em}, \varphi_{em}, \omega_{em})}{D_{ref}(\theta_{em}, \varphi_{em}, \omega_{em})}} \boxed{\frac{\sigma(\theta_{ex}, \varphi_{ex}, \omega_{ex})}{\sigma_{ref}(\theta_{ex}, \varphi_{ex}, \omega_{ex})}}$$

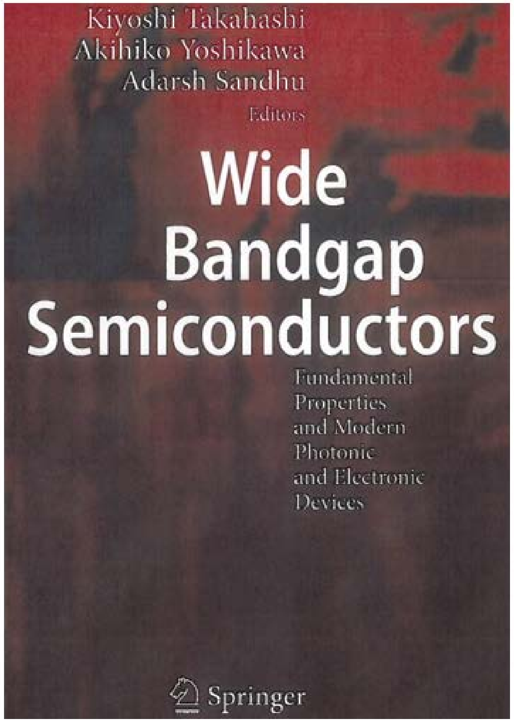
< 1 (~0.85)

x 10

x 5

Two final thoughts

Number of publications



2007

Lifetime of Research on Nitrides – Alone in the Wilderness

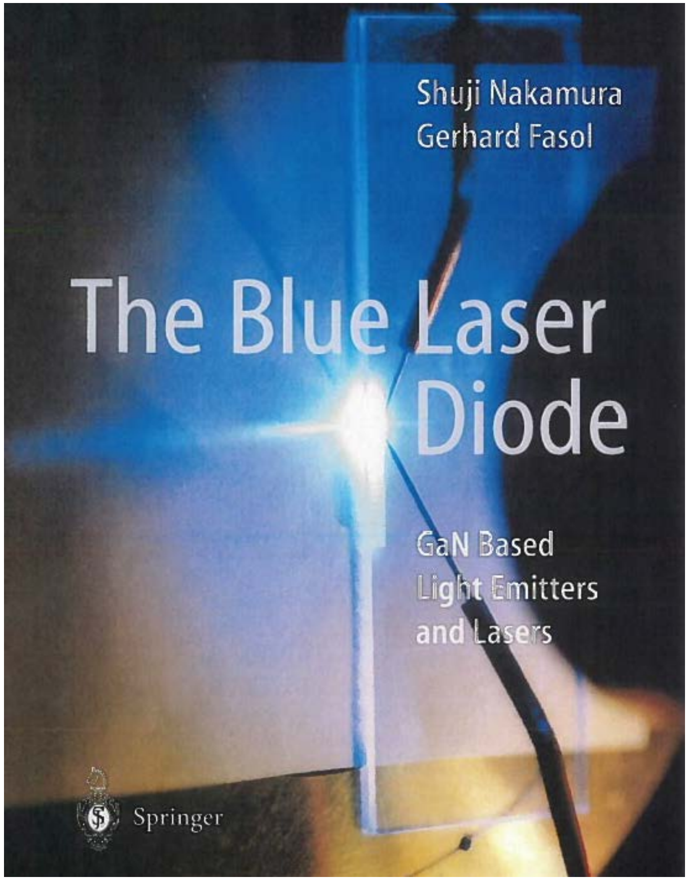
I. Akasaki

Blue light emitting devices fabricated using nitride semiconductors are ubiquitous. They are used in mobile phones, traffic signals and outdoor screens in soccer stadiums. The situation 30 years ago was a lot different when many groups withdrew from this subject of research due to unfavorable results. In spite of the lack of progress in this field at the time, I made a conscious decision to make research on nitride semiconductors my life work. This is a recollection of my thoughts and memories about my contribution to the blue renaissance [1–3]. I hope that the mistakes and moments of jubilation will inspire young scientists and engineers to have confidence in your own beliefs, not be swayed by trends and fashions, and move forward with passion and commitment.

The research of Akasaki, Nakamura and Amano will be almost impossible now:

- Quick results and high short term impact: Glossy journals.
- Impact factor of the journal where results are published has become more important than the long term impact of the research: Promotions, university evaluations, funding agencies, researchers.

Two final thoughts



1997

2.6 Why Did Nichia Succeed Where Many Much Larger Multinationals and Research Groups Failed?

work did play a major role.

As always, the key to Nichia's success is people. In Nichia's case these are just two: Shuji Nakamura and Nichia's chairman Nobuo Ogawa. It is important to keep in mind, that Nichia's management structure is extremely simple. In the case of Nichia's gallium nitride program, the 'management structure' consists of Ogawa, and Shuji Nakamura, and nobody else. It could not be more simple: no committees, no management boards, no advisors, no supervisors, no department heads, groups leaders etc., no review panels, no internationalization, no coordinators, no national or international consortia, no coordination – just work.

...Nichia's chairman, N. Ogawa, gave Dr. Nakamura and two assistants

Large companies are more likely to avoid risks and tend to take a more conservative approach to research – even in fundamental research. One reason, is that in many companies, government research programs and often even in Universities the real decisions are taken by administrators and not by researchers – a totally different kind of person to Ogawa, who knows what kind of risks are necessary to achieve research success. There is ample evidence that many fundamental research laboratories of major multinationals in 'blue sky' areas of research tend to perform 'main stream' research, i.e. research work which parallels that of many other groups, avoiding to a large extent the kind of out-of-the-ordinary, high-risk projects, which Nakamura at Nichia embarked upon when work on gallium nitride was started, an area which all competitors (with one or two exceptions) had abandoned in favor of II-VI materials.

- Alexei Halpin
- Mohammad Ramezani
- Shaojun Wang
- Quynh LeVan
- Niels van Hoof
- Said Rodriguez
- Gabriel Lozano
- Giuseppe Pirruccio
- Marc Verschuuren
- Manuela Lunz
- Dick de Boer
- Remco van Brankel