Thursday, November 6, 2014
16:15-17:15

"Tsinghua Global Vision Lectures"

Development of blue LEDs and their future prospects

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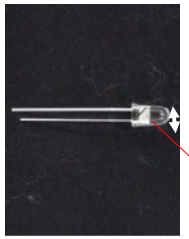
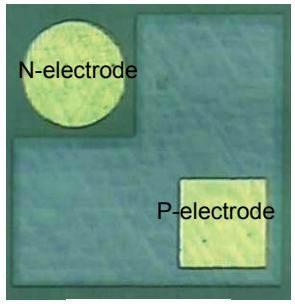
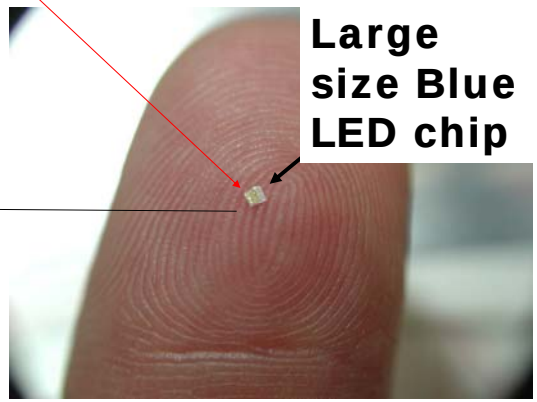
What is LED ?



5mm



0.3mm



Large size Blue LED chip

History of lighting

Solid state lighting

1962 Commercial LED
4th generation

Energy transfer (quantum mechanics)

1926 Fluorescent lamp
3rd generation

Blackbody emission
(early stage of quantum mechanics)

1879
incandescent lamp
2nd generation

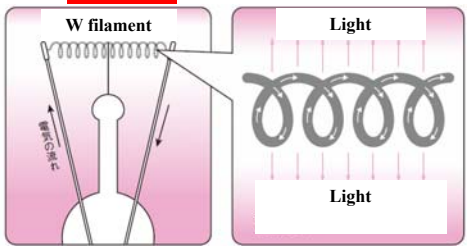
~19C fire
1st generation

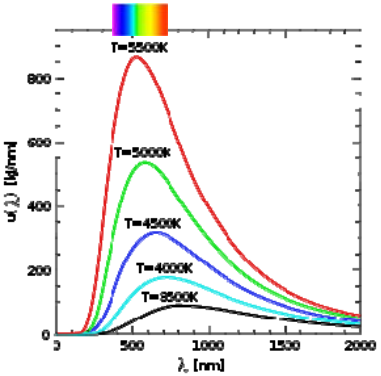
Chemical reaction

http://www.gijyutu.com/kyouzai/mokei/ohki2/light.htm
http://kagakukan.toshiba.co.jp/history/1goki/1940fluorescent.html
http://www.pawanavi.com/topics/2002/11/06/
http://www.audio-q.com/tyuumon.htm

Operating principle of incandescent lamp

3000℃



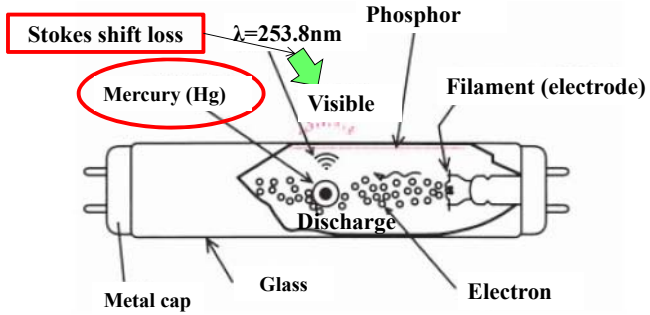


Blackbody spectrum

* Efficient in IR region
  Efficiency in visible region <20 lm/W
* Short lifetime
* Perfect color rendering

http://page.cextension.jp/c3079/pageview/pdf/0310.pdf
http://lamp1.com/product/category/denkyu/クリア電球/110v_c

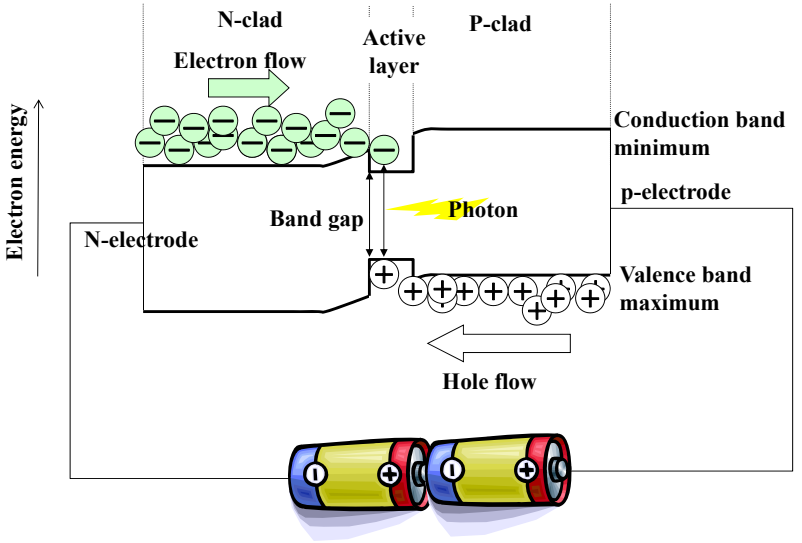
Operating principle of fluorescent lamp



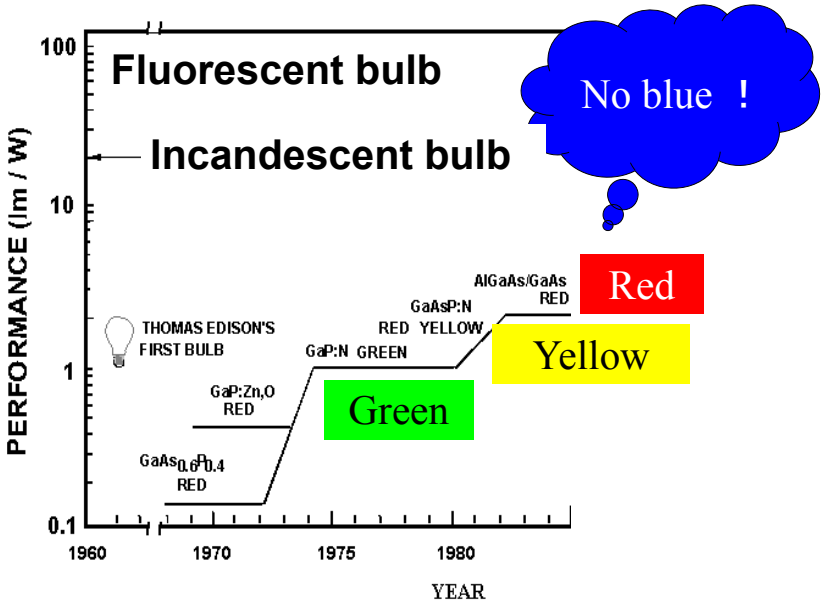
http://www.jelma.or.jp/05tisiki/pdf/guide_flu_02.pdf

* Efficiency is higher than that of incandescent lamp, but it is limited by Stokes shift loss ＜120 lm/W
* Lifetime is limited by ion bombardment.
* Hg is inevitable.

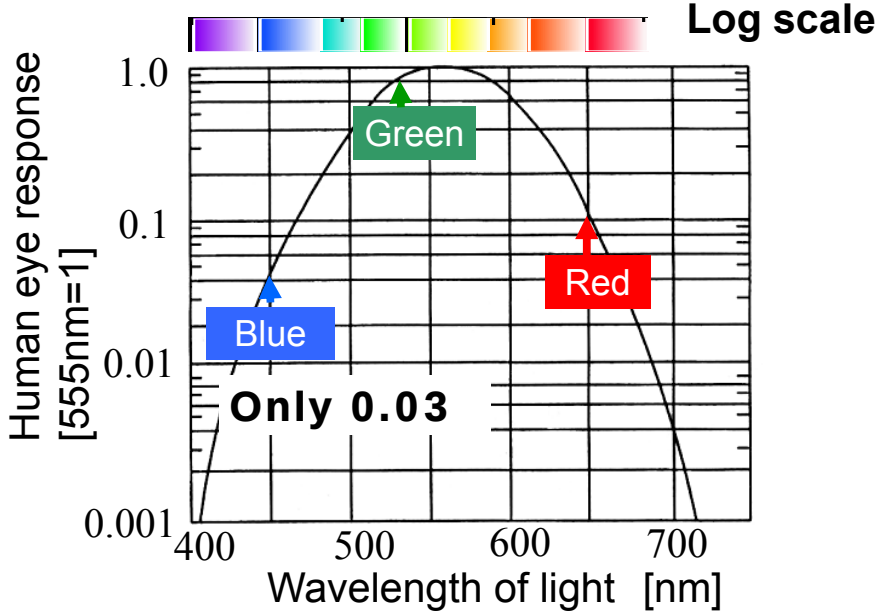
Operating principle of LED



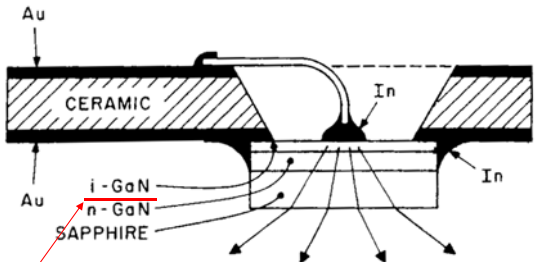
LED performance in the early 1980's



Why blue was so difficult ?



Why blue was so difficult ?



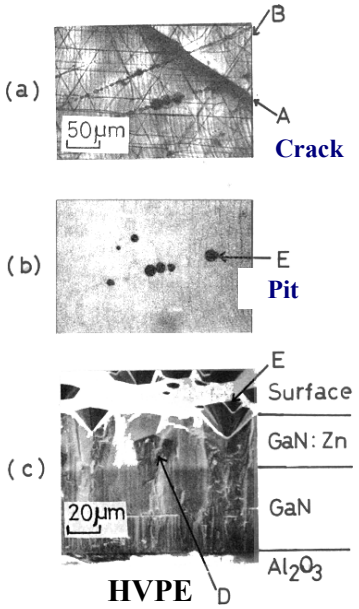
First GaN LED (mis type)

Efficiency : 10^{-5}～3×10^{-4}

p-GaN could not be grown.

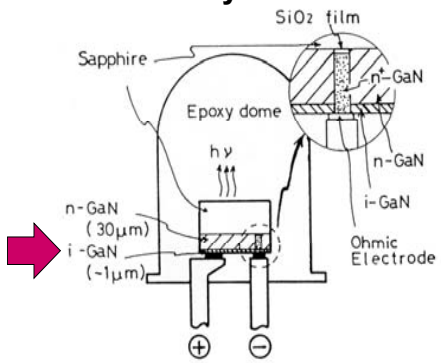
J. I. Pankove, E. A. Miller, D. Richman and J. E. Berkeyheiser: J.Lumin. 4 (1971) 63.

Why blue was so difficult ?



GaN on Sapphire by HVPE in early 1980's

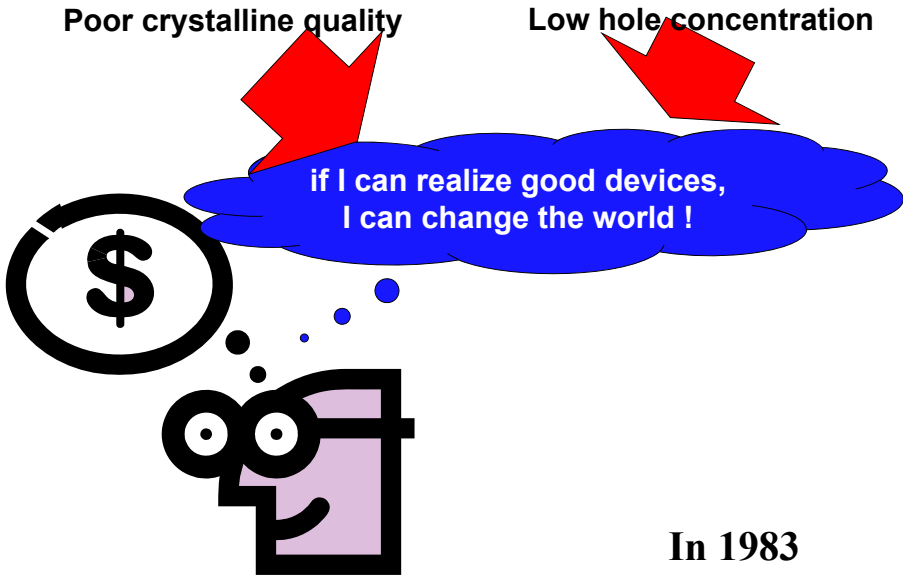
Efficiency: ～0.12 %



1981 Flip-chip configuration

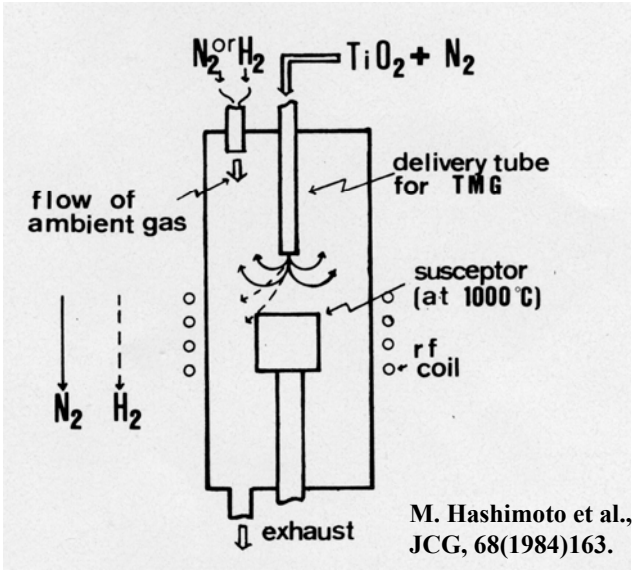
Y. Ohki, Y. Toyoda, H. Kobayashi and I. Akasaki, Inst. Phys. Conf. Ser., 63(1981)479.

Some young researcher expected that …



In 1983

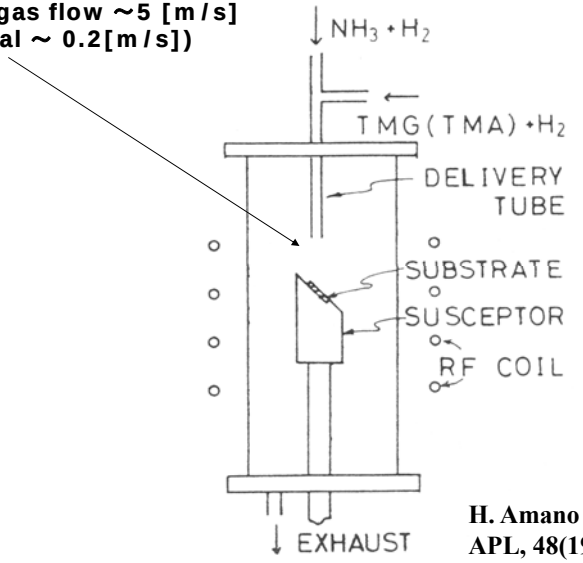
Development of the MOVPE reactor



M. Hashimoto et al., JCG, 68(1984)163.

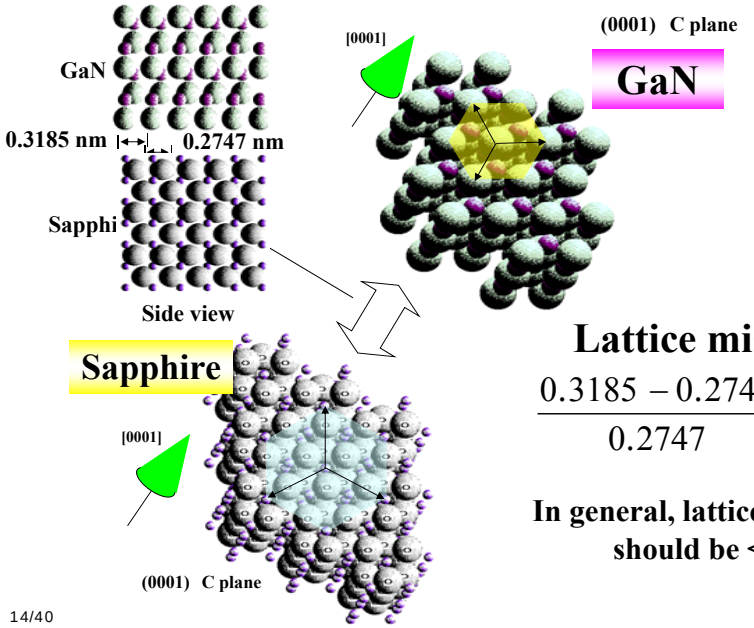
Development of the MOVPE reactor

High speed gas flow ~5 [m/s]
(conventional ~ 0.2[m/s])



H. Amano et al.,
APL, 48(1986)353.

Why it was so difficult to grow high quality GaN?

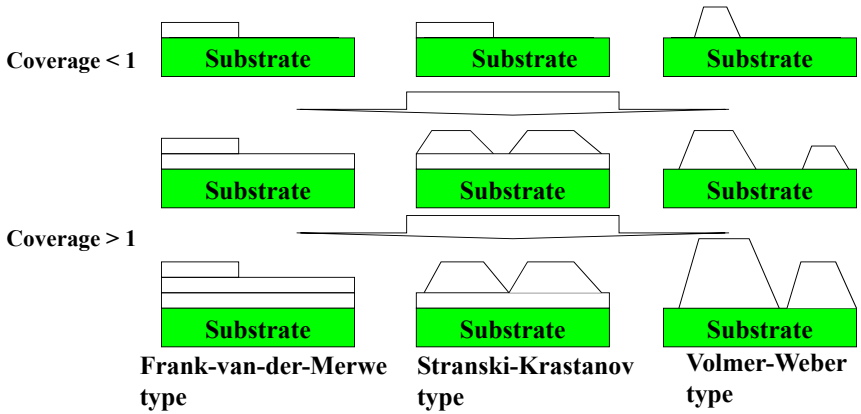


Lattice mismatch

$$\frac{0.3185 - 0.2747}{0.2747} \approx +16\%$$

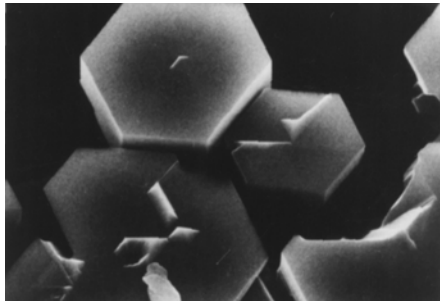
In general, lattice mismatch should be <1%.

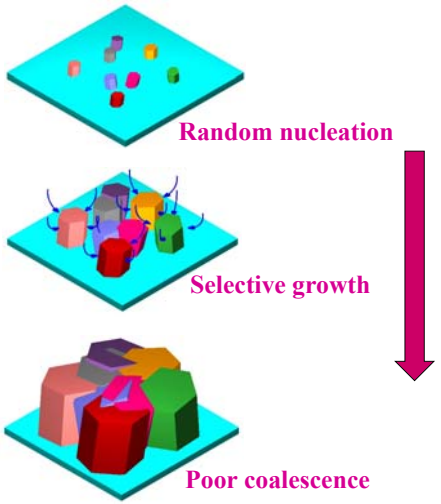
Why it was so difficult to grow high quality GaN?



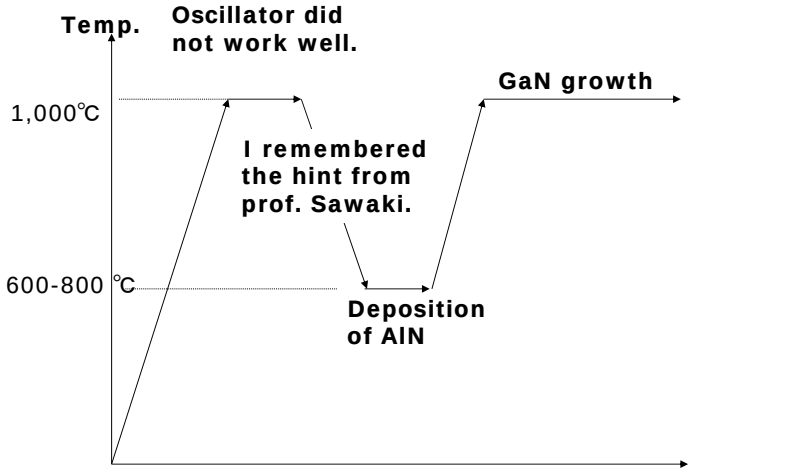
Lattice mismatch

Why it was so difficult to grow high quality GaN?





Low temperature deposited buffer layer

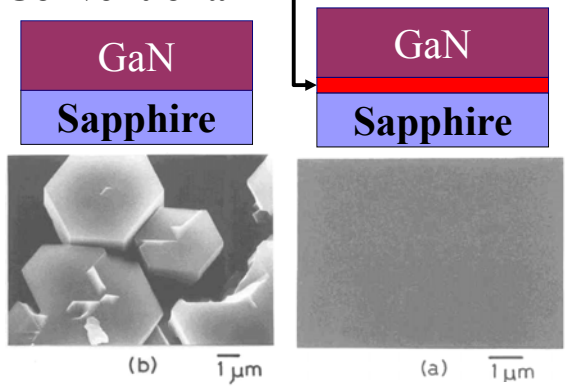


Substrate temperature should be higher than 1200℃ for the epitaxial growth of AlN.

Low temperature deposited buffer layer

1985 LT buffer

Conventional



w/o LT buffer

w LT buffer

H. Amano et al., APL, 48(1986)353.

Low energy electron beam irradiation

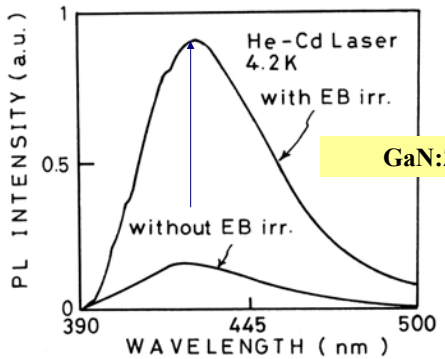


FIGURE 3

The dependence of annealing time on PL(430nm) intensity

GaN:Zn

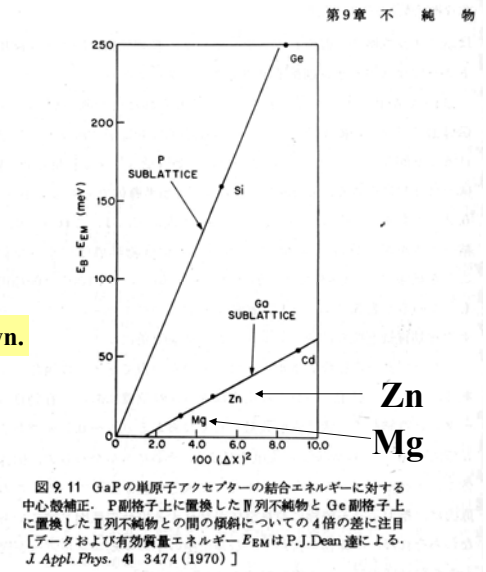
Highly resistive, but….

H. Amano et al.,
J. Lumin. 41&42(1988)121.

Selection of best dopant

Selection of the dopant
(Zn× Mg○)

Highly resistive when it was as grown.



Zn

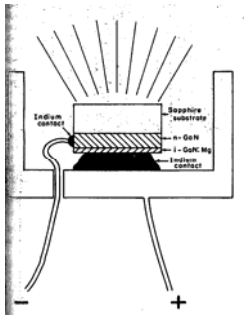
Mg

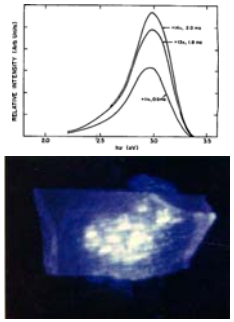
図 9.11 GaPの単原子アクセプターの結合エネルギーに対する中心殻補正．P副格子上に置換したⅣ列不純物とGe副格子上に置換したⅡ列不純物との間の傾斜についての4倍の差に注目［データおよび有効質量エネルギー E_{EM} はP.J.Dean 達による．*J. Appl. Phys.* **41** 3474 (1970)］

History of Mg

Violet luminescence of Mg-doped GaN

H. P. Maruska, D.A. Stevenson, J. I. Pankove, *Appl. Phys. Lett., 22, 303 (1973).*



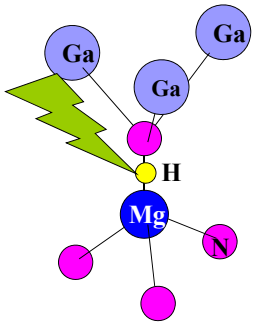


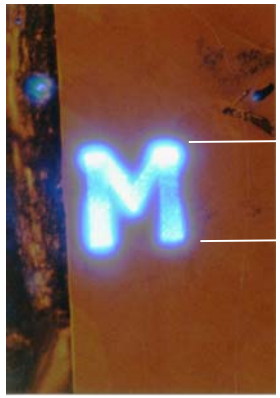
World's first violet LED based on Mg-doped GaN.

Will blue LEDs ever make Maruska a rich man?

http://www.sslighting.net/lightimes/features/maruska_blue_led_history.pdf

Realization of p-type GaN by Mg-doping followed by LEEBI





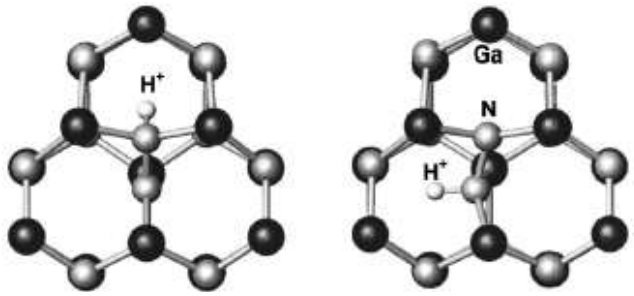
H. Amano et al., JJAP 28(1989)L2112.

1992 Thermal annealing
S. Nakamura et al., JJAP 31(1992)1258.

Mechanism

Hydrogen passivation of acceptor

Van Vechten et al., JJAP 31(1992)3662.

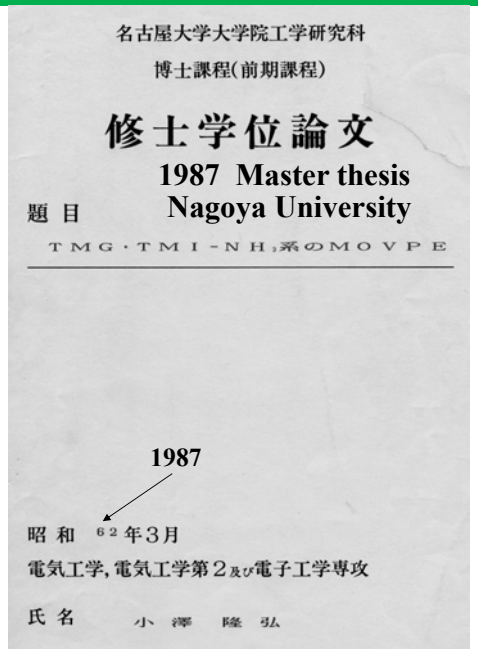


Lattice location of hydrogen in Mg doped GaN

W. R. Wampler,[a] S. M. Myers, A. F. Wright, J. C. Barbour, C. H. Seager, and J. Han
Sandia National Laboratories, Albuquerque, New Mexico 87185-1056

JAP, 90(2001)108.

Missing fortune InGaN



名古屋大学大学院工学研究科
博士課程(前期課程)

修士学位論文

1987 Master thesis
Nagoya University

題目 TMG・TMI-NH$_3$系のMOVPE

1987

昭和 62年3月
電気工学, 電気工学第2及び電子工学専攻
氏名 小澤 隆弘

Person who grasped the future

1989

Inst. Phys. Conf. Ser. No 106: Chapter 3
Paper presented at Int. Symp. GaAs and Related Compounds, Karuizawa, Japan, 1989

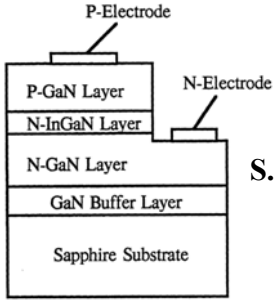
1989(NTT)

Wide-gap semiconductor (In,Ga)N

T. MATSUOKA, *H. TANAKA, T. SASAKI and A. KATSUI

NTT OPTO-ELECTRONICS LABORATORIES
Tokai, Ibaraki, 319-11 JAPAN
**NTT APPLIED ELECTRONICS LABORATORIES*
Musashino, Tokyo, 180 JAPAN

Company who grasped the future



NICHIA

S. Nakamura et al., JJAP, 32(1993)L8.

1993 World's first commercialization of nitride-LEDs

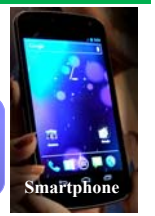
History of the development of blue LED in Japan

Isamu Akasaki
1981 Nagoya Univ.
1992- Meijo Univ.
(Prof. Emeritus Nagoya Univ.)

Widegap GaN
Blue LED

Shuji Nakamiura
(Nichia, now UCSB)

1989~1993:LT GaN
p-type by thermal annealing
InGaN/GaN DH



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LT buffer
P-type GaN

1989 JST
1995 Commercialization

Toyoda Gosei

Hiroshi Amano
1988 RA, Nagoya
1989 Dr. of Eng., Nagoya Univ.
1992-2010 Meijo Univ.
2010 Nagoya Univ.