

Monday, December 10, 2014

9:45 - 10:15

# Growth of GaN on sapphire by low temperature deposited buffer layer and realization of p-type GaN by Mg-doping followed by LEEBI treatment

- Messages to the younger generation -

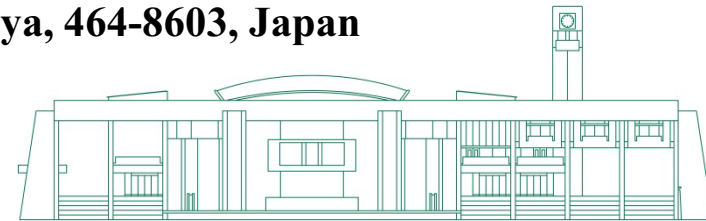


**Hiroshi Amano**

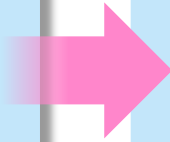
[amano@nuee.nagoya-u.ac.jp](mailto:amano@nuee.nagoya-u.ac.jp)

Graduate School of Engineering, Akasaki Research Center,  
Nagoya University

Furo-cho, Chikusa-ku, Nagoya, 464-8603, Japan



# How blue LED change our lives?



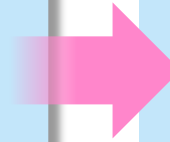
**1989**

**GAME BOY**  
1989 Released  
Photo : Nintendo Co., Ltd.



**1998**

**GAME BOY COLOR**  
1998 Released  
Photo : Nintendo Co., Ltd.



**1991**

**mova P**  
1991 Released  
Website : DOCOMO CS Tohoku,  
INC.  
Quoted from the history  
of the mobile phone  
<http://www.docomo-cs-tohoku.co.jp/museum/tanmatsu/p.html>



**1999**

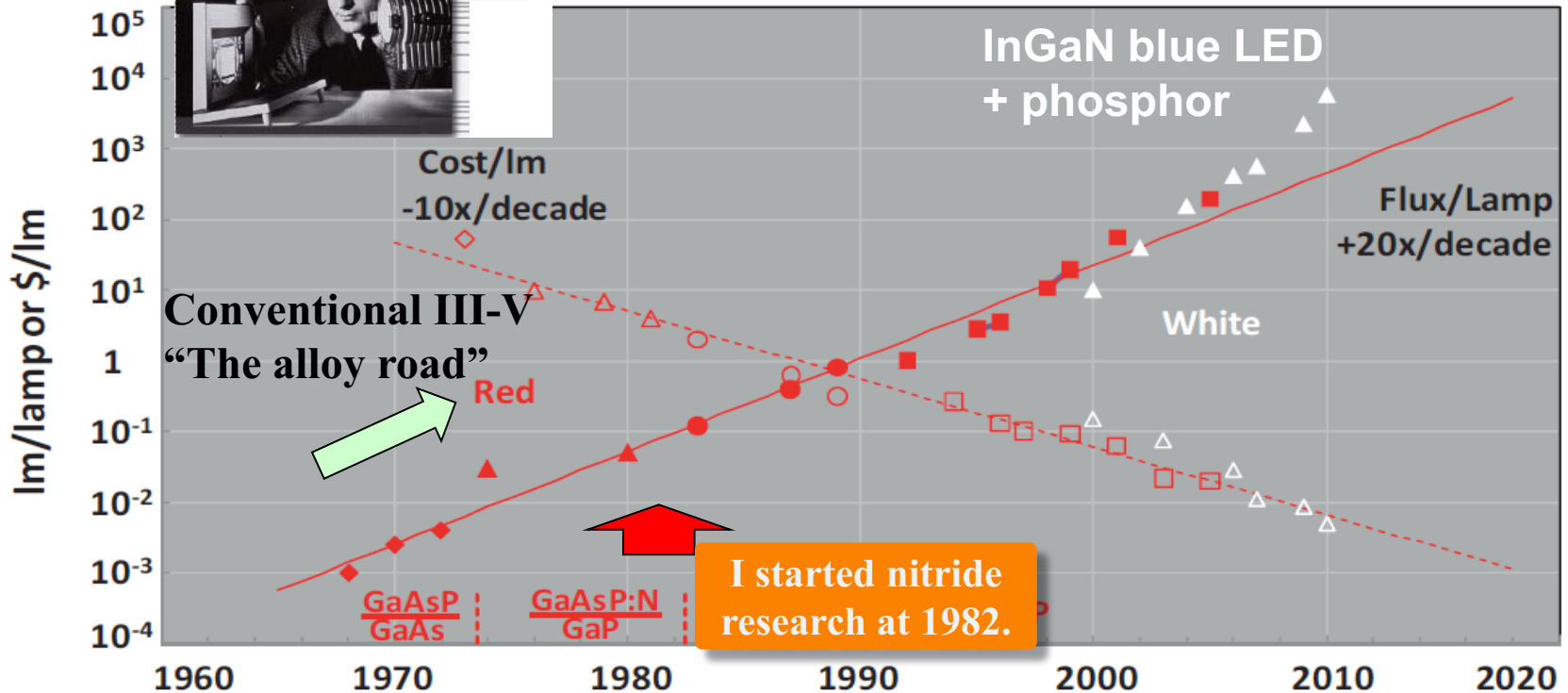
**Digital mova F502i HYPHER**  
1999 Released  
Website : DOCOMO CS Tohoku, INC.  
Quoted from the history  
of the mobile phone  
<http://www.docomo-cs-tohoku.co.jp/museum/tanmatsu/f502i.html>

# Overview of development LED

RCA社による液晶ディスプレイの試作発表(1968年)



## 1968 RCA LCD



R. Haitz and J. Y. Tsao, phys. stat. sol. (a)208(2011)17

1971 J. Pankove GaN mis LED

1962 N. Holonyak Jr., GaAsP red LD

1952 H. Welker GaAs, GaP

# Why I was interested in the blue LEDs?

1970

1967

Vapour-grown AlN  
Matsushita Research  
Institute



**Isamu Akasaki**

1992- Meijo Univ.  
(Prof. Emeritus Nagoya Univ.)

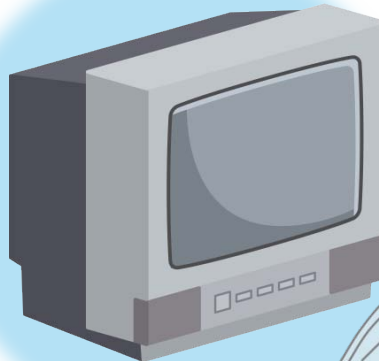
1980

1981

Nagoya Univ.

1982  
Undergraduate

Graduation Research  
“Nitride-Based Blue LED”



1990

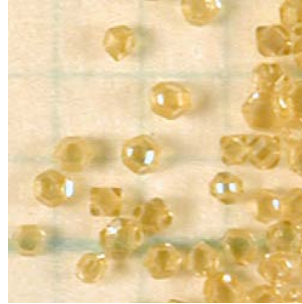
Size of  
Braun tube  
is too big !

if I can achieve  
blue LEDs,  
I can change  
the world !

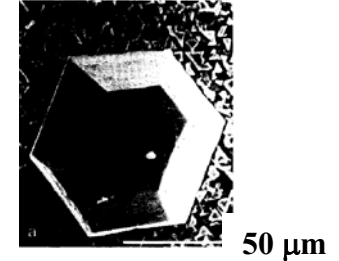
# Why it was so difficult to grow high quality GaN?

**Bulk Growth**

**Diamond**  
52,000 atm  
1,200°C

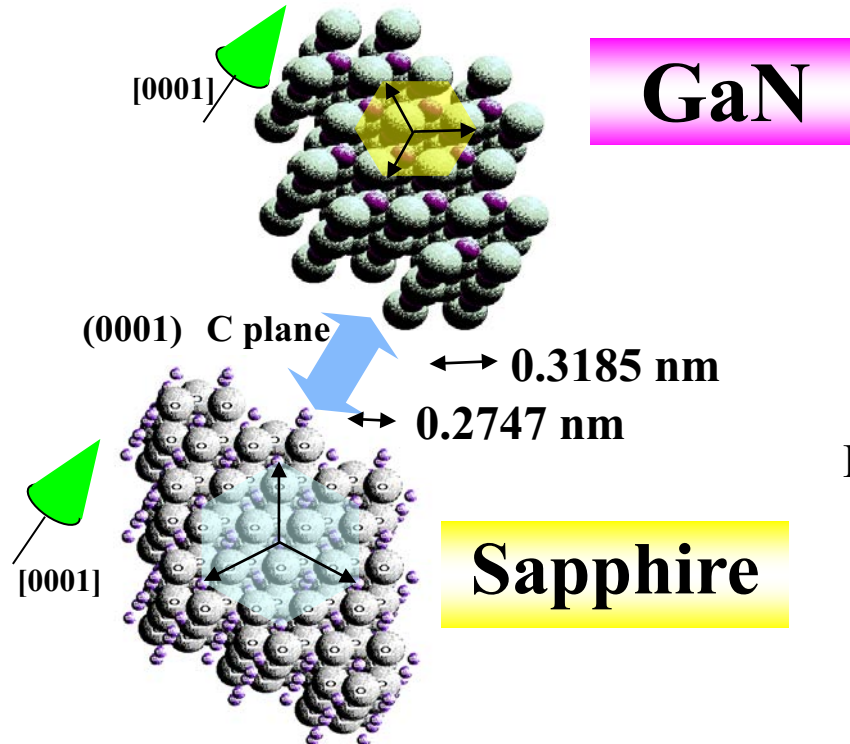


**GaN**  
45,000 atm  
2,530°C



J. Karpinski and S. Porowski, JCG, 66(1984)1.

**Thin film growth**

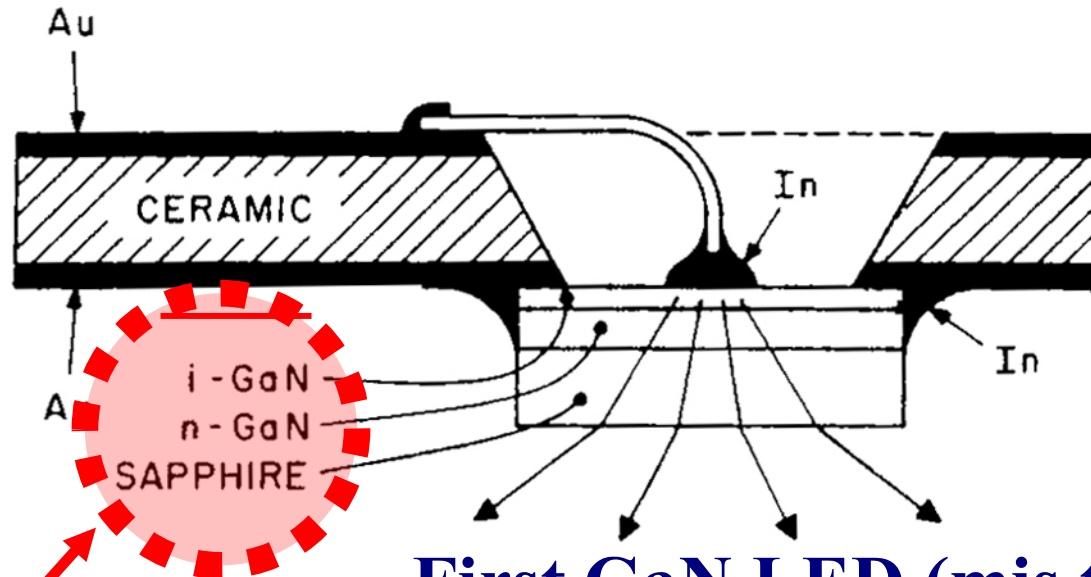


**Lattice mismatch**

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

**In general, lattice mismatch should be <1%.**

# Why nitride-blue LED was so difficult ?

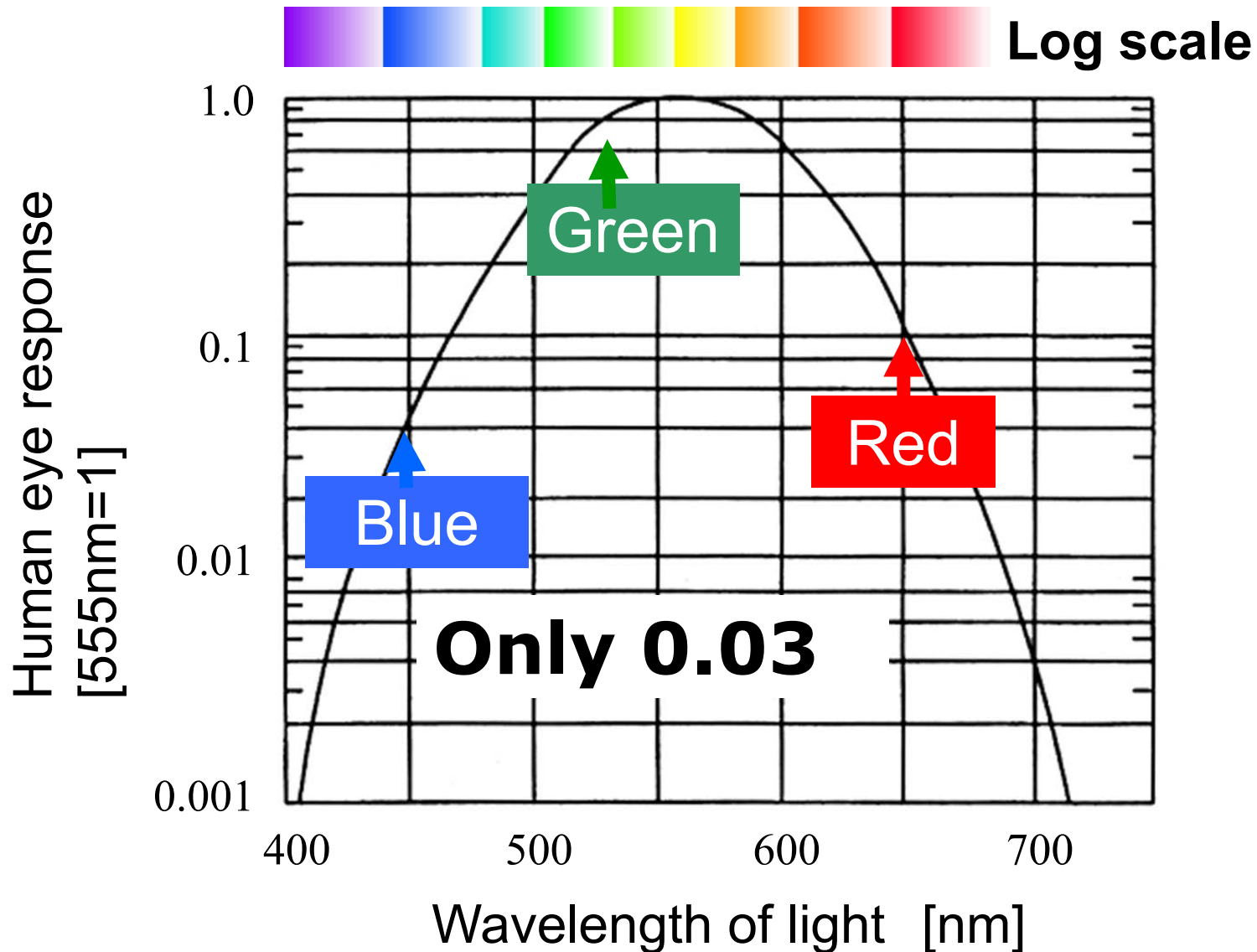


**First GaN LED (mis type)**  
**Efficiency :  $10^{-5} \sim 3 \times 10^{-4}$**

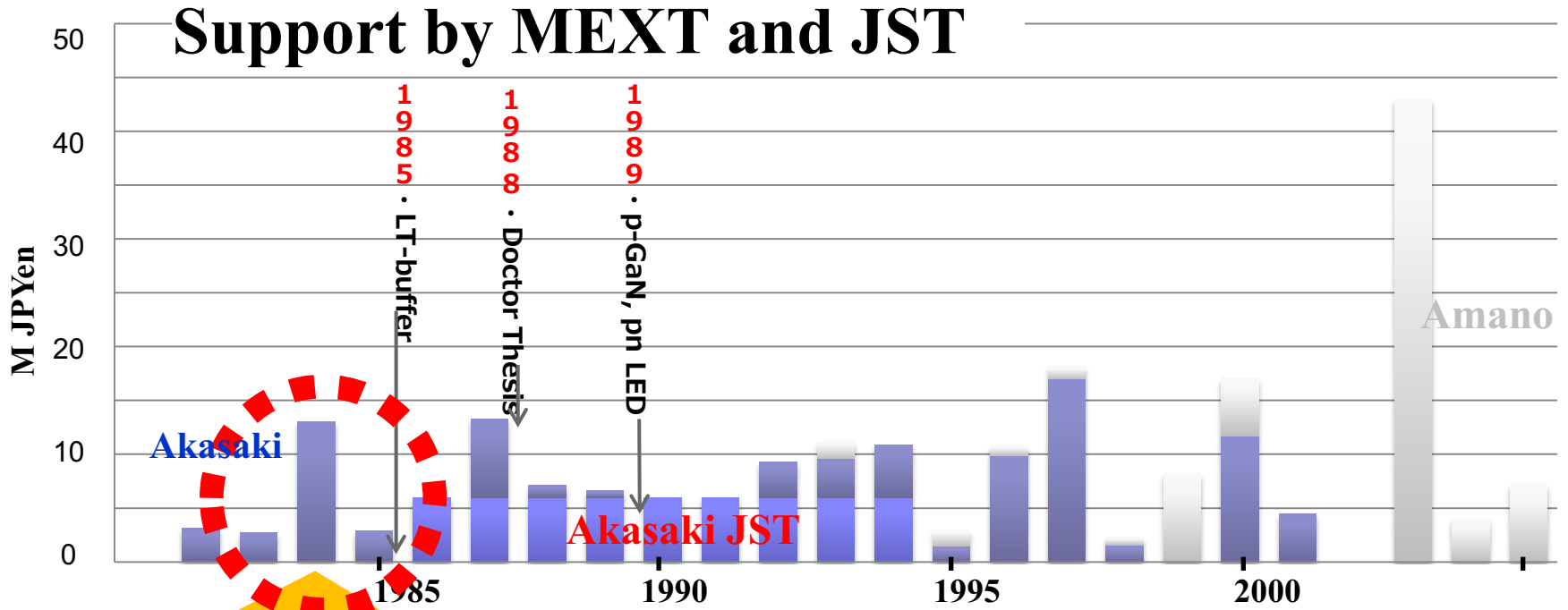
**p-GaN could not be grown.**



# Why blue was so difficult ?

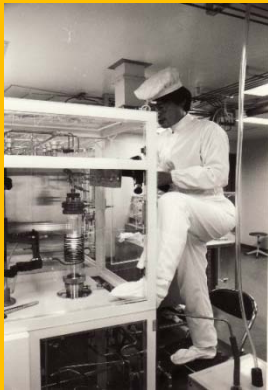


# Funding situation of the University in Japan in mid 80's



1US\$=115 JPYen

1984

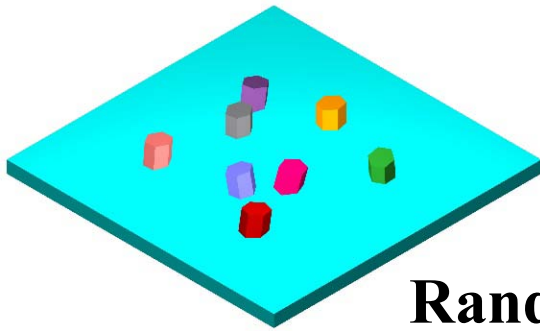


Measuring susceptor temperature by pyrometer

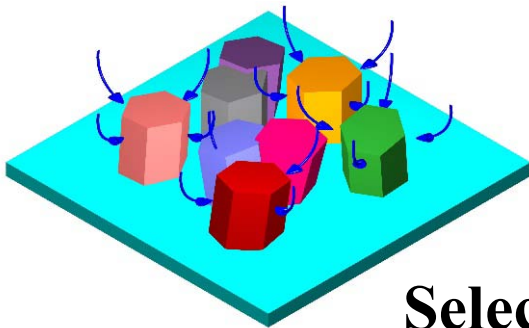
Handmade MOVPE Reactor



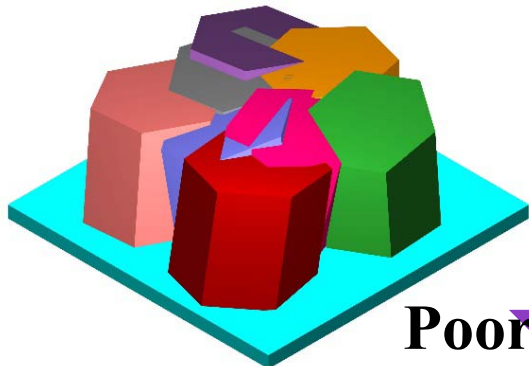
# Why it was so difficult to grow high quality GaN?



**Random nucleation**

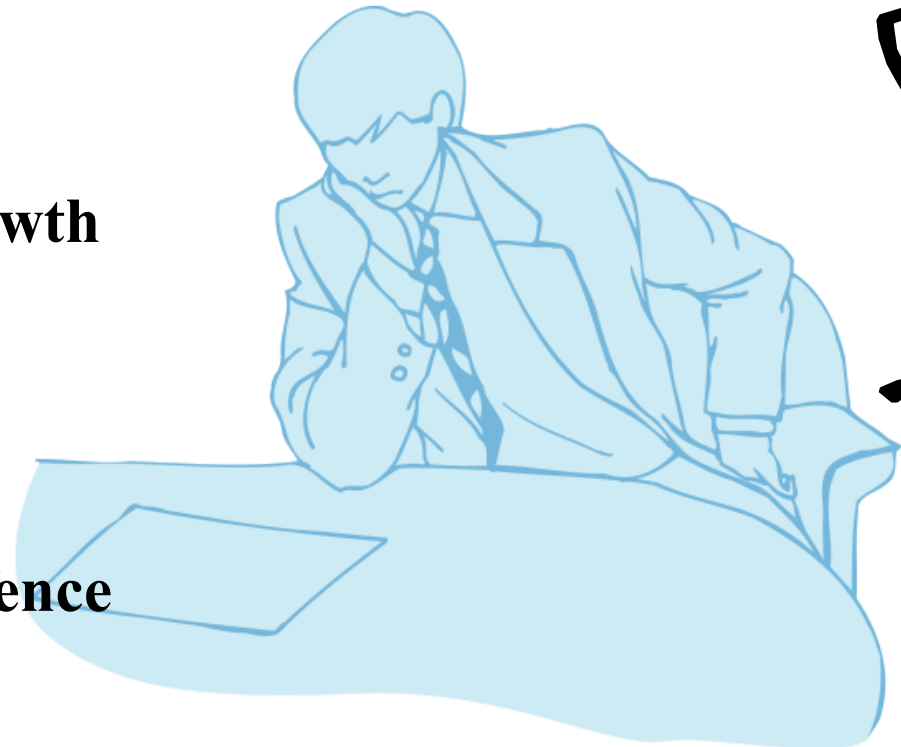


**Selective growth**

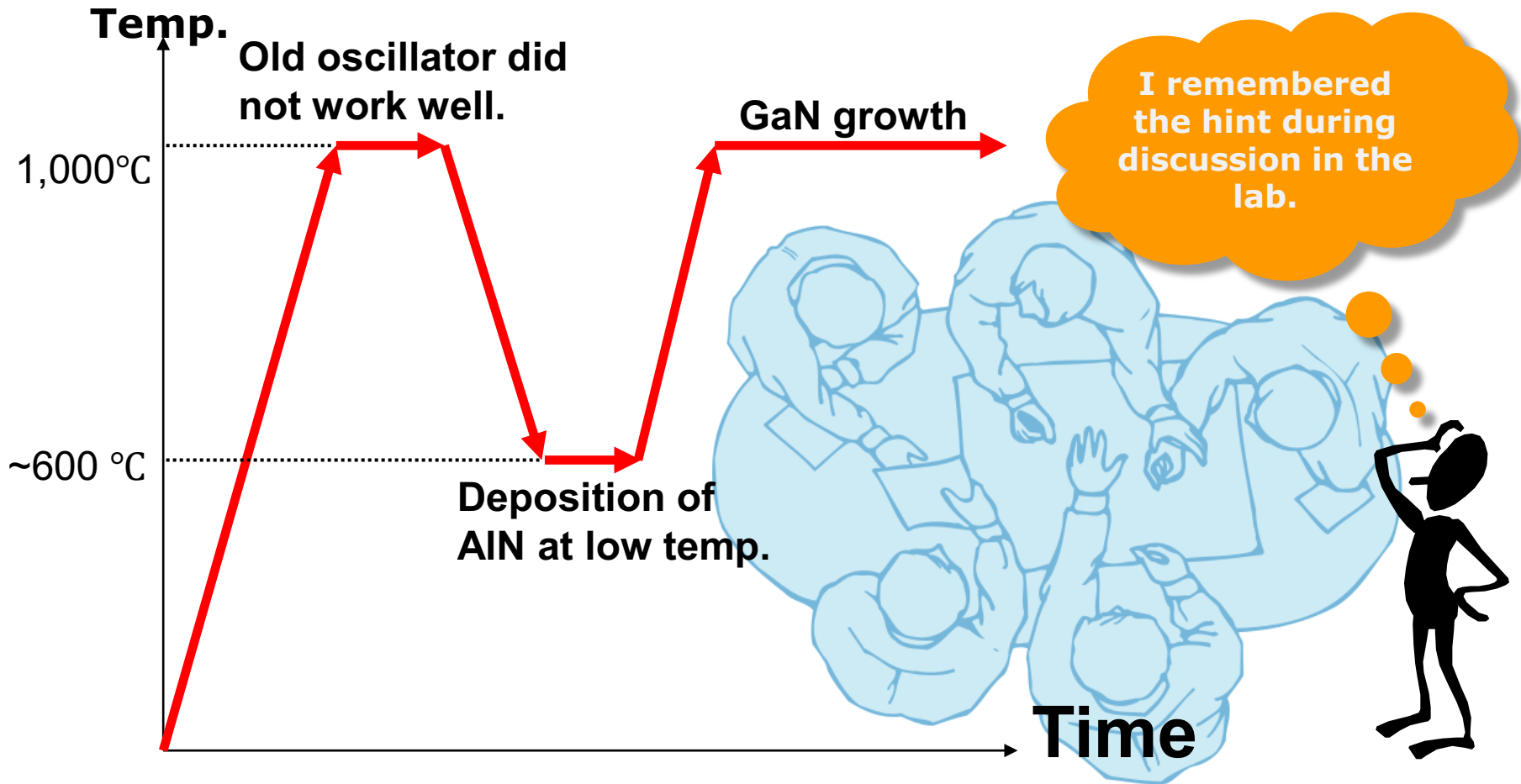


**Poor coalescence**

I have tried more than 1,500 times, but I could not get high quality GaN film.



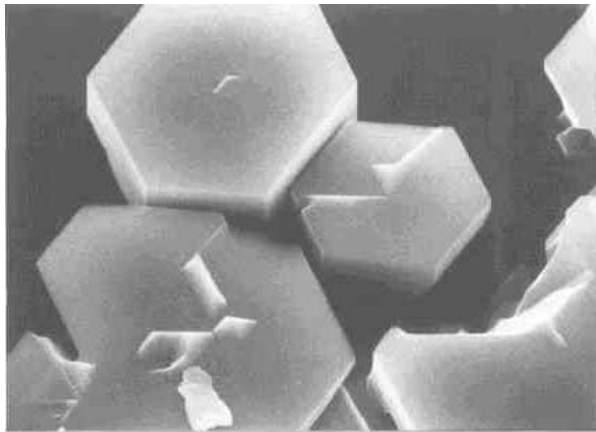
# Low temperature deposited buffer layer



**I knew that substrate temperature should be higher than 1200°C for the epitaxial growth of AlN.**

# Low temperature deposited buffer layer

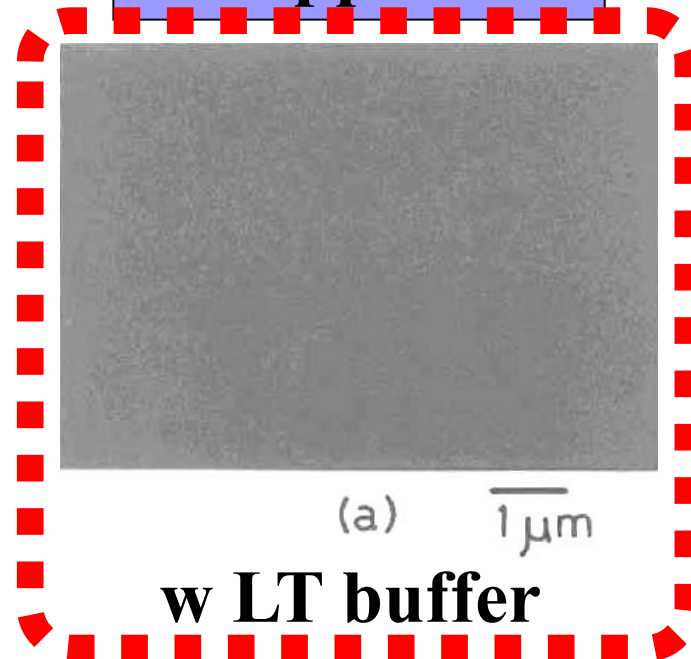
**Conventional**



(b)  $1\ \mu\text{m}$

**w/o LT buffer**

**1985 LT buffer**



(a)  $1\ \mu\text{m}$

**w LT buffer**

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

# Low energy electron beam irradiation (LEEBI)

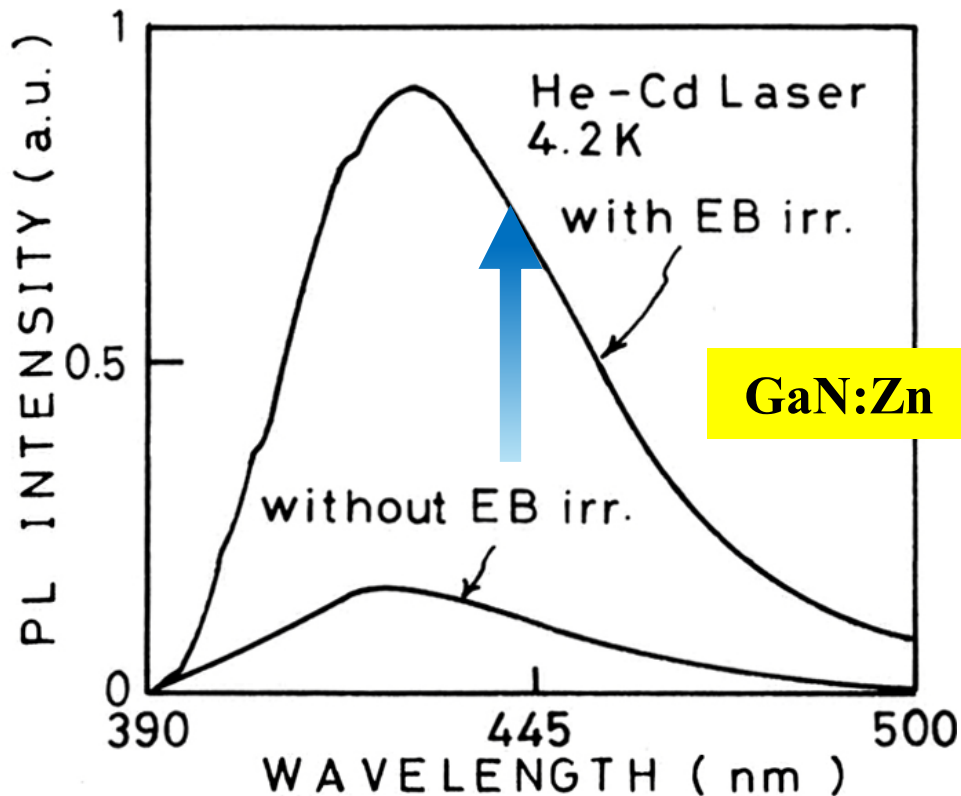


FIGURE 3

**Highly resistive**

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

At JSAP annual meeting presentation, only four people including prof. Akasaki, chairman and I were in the room.



# Selection of best dopant

## Selection of the dopant (Zn × MgO)

Highly resistive when it  
was as grown.

J. Philips, "Bonds and Bands in Semiconductors"

第9章 不 純 物

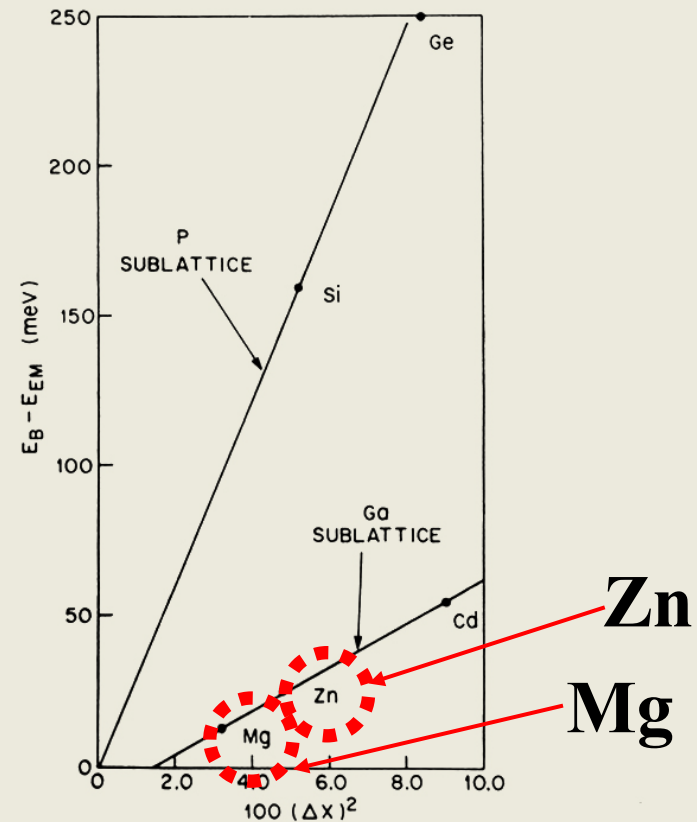


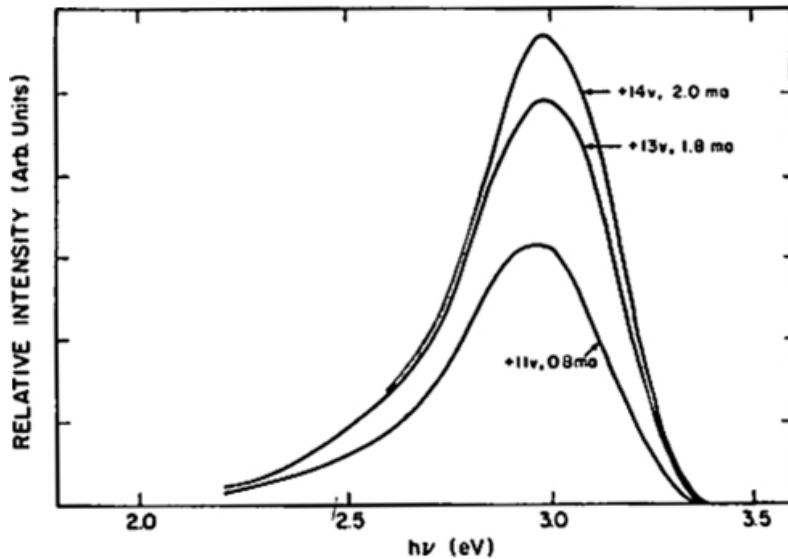
図 9.11 GaPの単原子アクセプターの結合エネルギーに対する中心殻補正. P副格子に置換したⅣ列不純物とGe副格子に置換したⅡ列不純物との間の傾斜についての4倍の差に注目 [データおよび有効質量エネルギー  $E_{EM}$  はP.J.Dean 達による. *J. Appl. Phys.* 41 3474 (1970) ]

# History of Mg

## Violet luminescence of Mg-doped GaN

**H. P. Maruska, D.A. Stevenson, J. I. Pankove,**

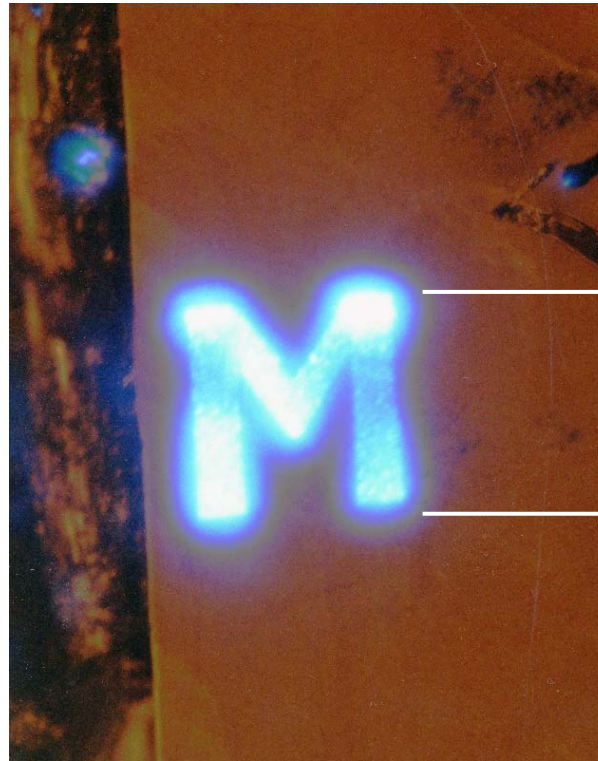
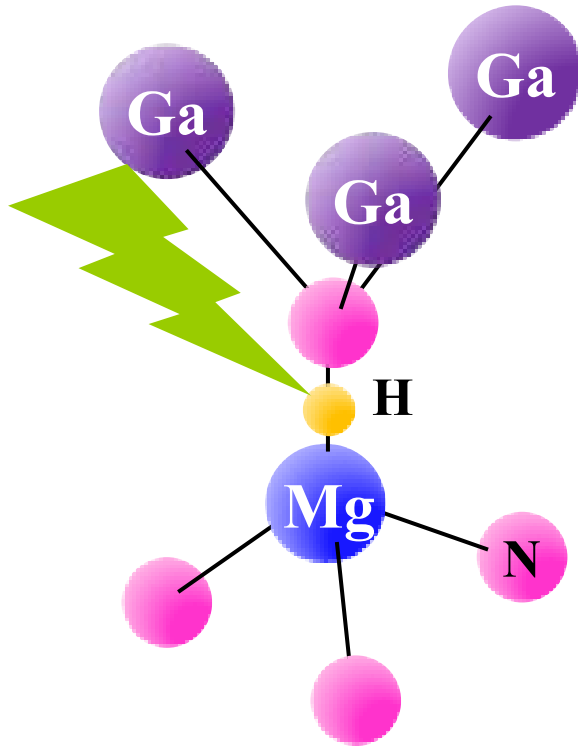
Appl. Phys. Lett., 22, 303 (1973).



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



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



50 μm

**H. Amano**

et al., JJAP  
28(1989)L2112.



**1992 Thermal annealing**

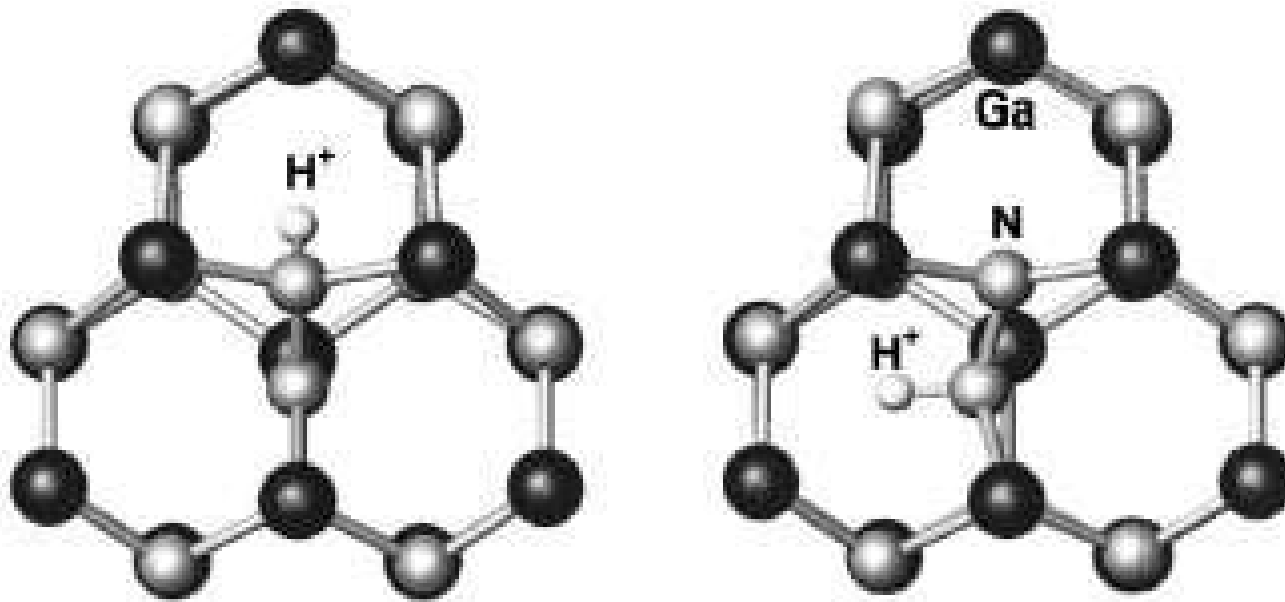
**S. Nakamura**

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,<sup>a)</sup> 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.

# Good fortune that we missed -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<sub>3</sub>系のMOVPE

1987

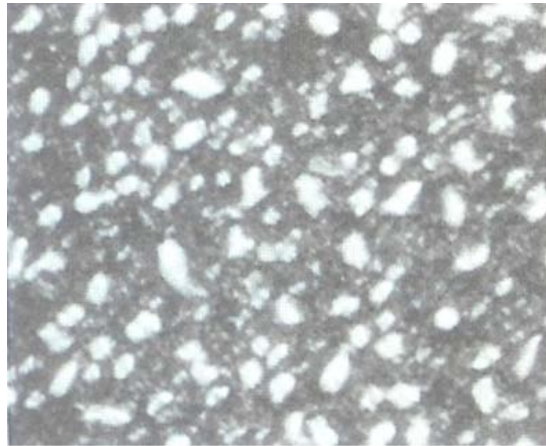
昭和 62 年3月

電気工学, 電気工学第2及び電子工学専攻

氏名 小澤 隆弘

# Important finding

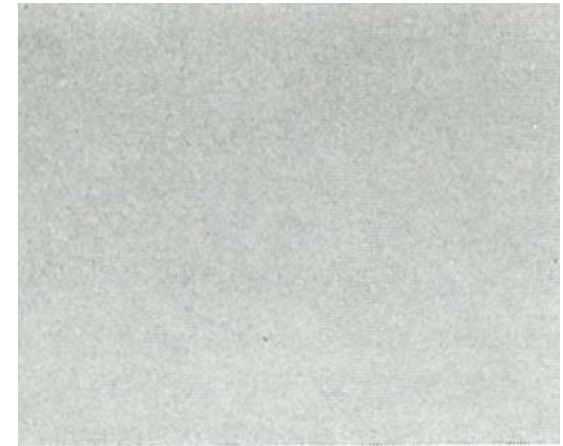
1989



(a)  $V / III = 16000$



(b)  $V / III = 80000$



(c)  $V / III = 165000$

Inst. Phys. Conf. Ser. No 106 : Chapter 3

Paper Presented at Int. Symp. GaAs and Related Compounds, Karuizawa, Japan, 1989

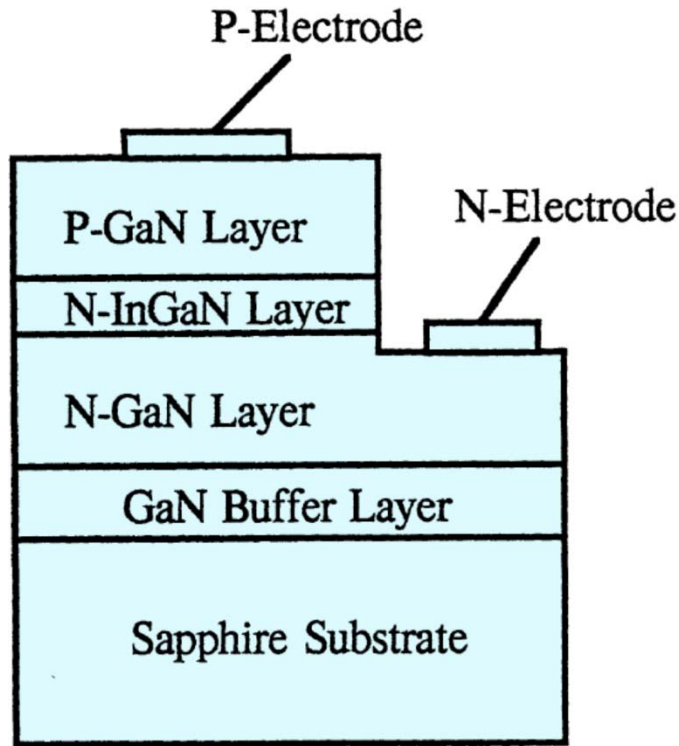
**Wide-gap semiconductor (In,Ga)N**

**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 and people who grasped the fortune



**S. Nakamura**

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

**1993 World's first  
commercialization of nitride-LEDs**

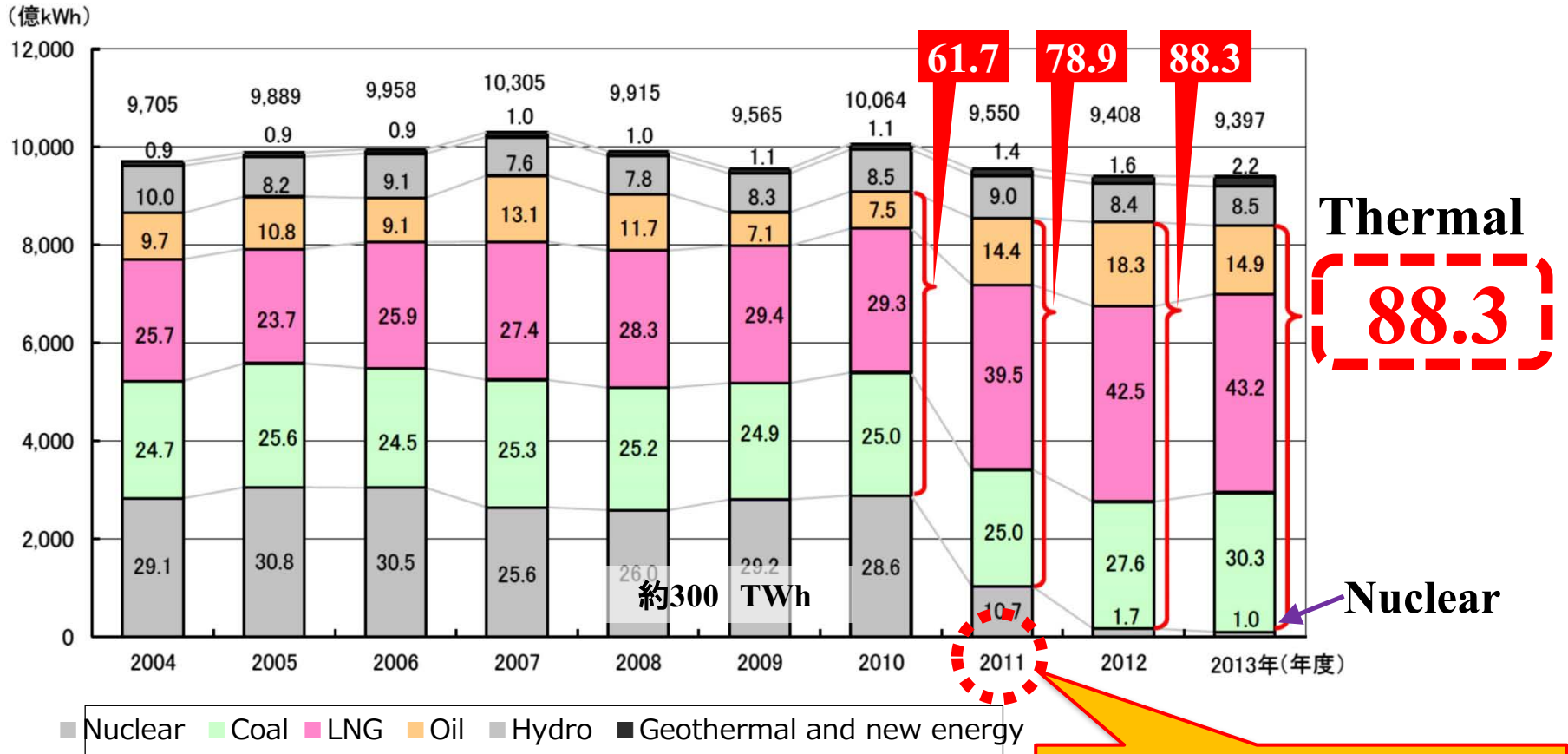


# How InGaN LEDs contribute to energy savings ?

2014.5.23

The Federation of Electric Power Companies of Japan

## Electricity generation in Japan

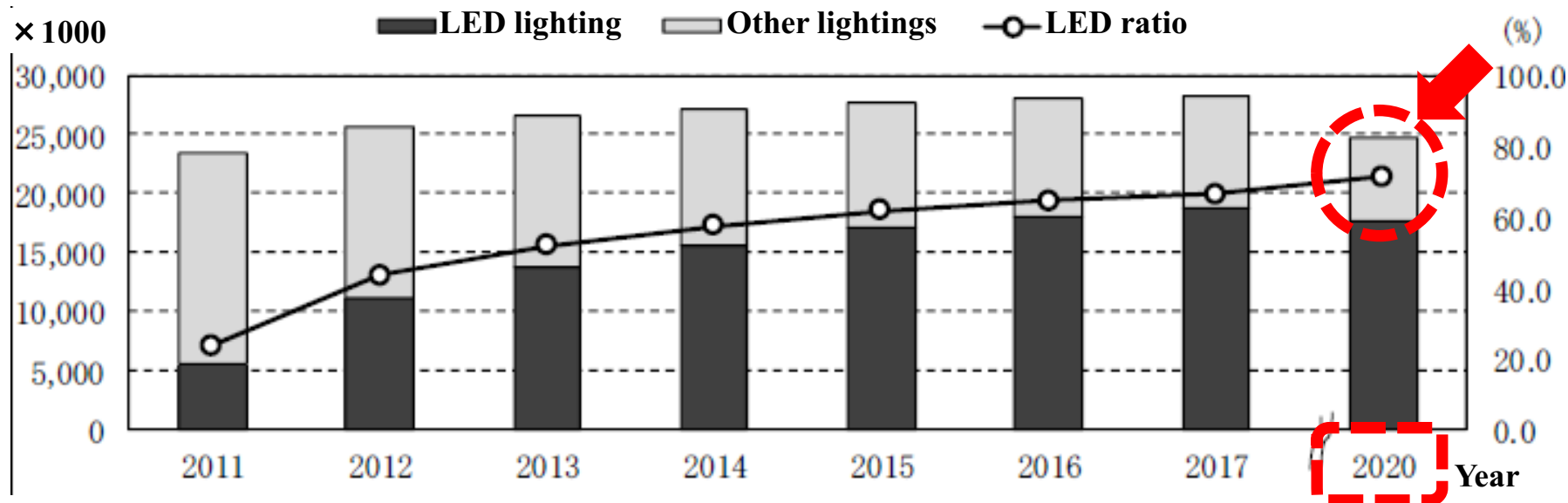


(注) 10 電力計、他社受電分を含む。石油等にはLPG、その他ガスを含む。  
 グラフ内の数値は構成比(%)。四捨五入の関係により構成比の合計が100%にならない場合がある。

[http://www.fepec.or.jp/about\\_us/pr/pdf/kaiken\\_s1\\_20140523.pdf](http://www.fepec.or.jp/about_us/pr/pdf/kaiken_s1_20140523.pdf)



# Forecast of ratio of LED lighting in Japan



Data from Fuji Chimera Research Institute, Inc.,  
2014 LED Related Market Survey

**In Japan, we can save about 7%  
(=1,000,000,000,000 JP Yen)  
of the total energy consumption by 2020.**

# Lighting for the younger generation



# Message to the younger researchers



**Isamu Akasaki**

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

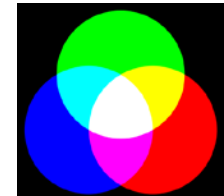
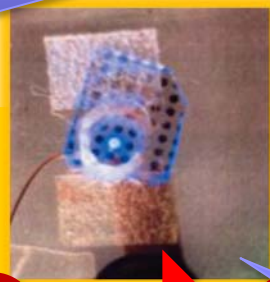
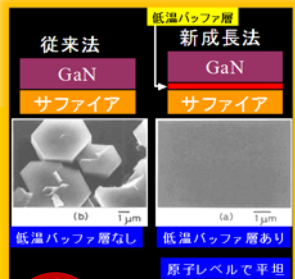
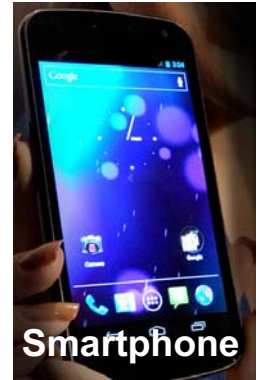
Widegap GaN Blue LED



**Shuji Nakamiura**

(Nichia, now UCSB)

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



Three primary colors

1980

1985

1990

1995

1985 LT buffer (Master course)  
1989 P-type GaN (Research Associate)

1989 JST  
1995 Commercialization

Toyoda Gosei

**Hiroshi Amano**

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



1999 :  
White LED

Yellow Phosphor



© Rotatebot

# Acknowledgements

## ***Akasaki Laboratory, Nagoya University (1982-1992)***

---

**Isamu Akasaki, Nobuhiko Sawaki, Kazumasa Hiramatsu, Shigeru Tamura  
Atshushi Shimizu, Yasuo Koide, Kenji Itoh, Takahiro Kozawa, Masahiro Kito,  
Kouichi Naniwae**

## ***Meijo University (1992-2010)***

---

**Isamu Akasaki, Satoshi Kamiyama, Tetsuya Takeuchi, Motoaki Iwaya  
Students of Akasaki and Amano Laboratory, Staff of Meijo University**

## ***Nagoya University (2010- )***

---

**Masahito Yamaguchi(passed away at 2013) , Yoshio Honda, Guangju Ju,  
Kaddour Lekhal, Siyoung Bae, Students of Amano and Honda Laboratory,  
Aki Eguchi, Masako Yasui, Yoko Tatsumi, Tomoko Hosoe**

**The President of Nagoya University Michinari Hamaguchi**

**Vice presidents; Ichiro Yamamoto, Ryoichi Fujii, Masanori Aikyo,**

**Hideyo Kunieda, Yoshihito Watanabe, Yasuo Suzuoki,**

**Seiichi Matsuo, Katsuya Ichihashi**

**All the staff of Nagoya University**

# Acknowledgements

## *Toyoda Gosei*

---

**Koichi Ota, Naoki Shibata, Nobuo Okazaki, Katsuhide Manabe,  
Michinari Sassa, Hisaki Kato, Masahiro Kotaki,  
All the staff of Toyoda Gosei  
The President Tadashi Arashima**

## *Toyota Central R&D Labs.*

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**Masafumi Hashimoto**

## *UVCR and Nikkiso*

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**Akira Hirano, Masamichi Ipponmatsu, Cyril Pernot,  
Hidemasa Tomosawa, All the staff of Nikkiso Giken  
The President Toshihiko Kai**

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*Kasumi,  
Aya and Mitsuru Amano*