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 -

名古屋大学 NAGOYA UNIVERSITY

Hiroshi Amano

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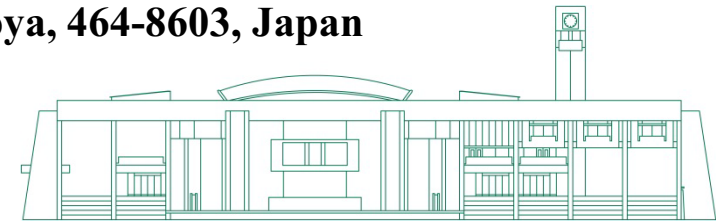
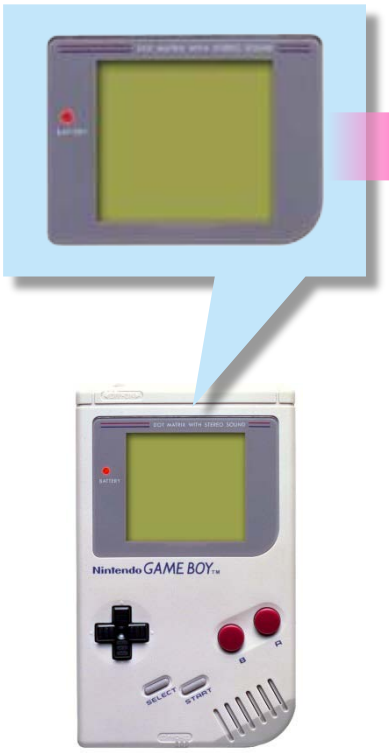
Graduate School of Engineering, Akasaki Research Center, Nagoya University
Furo-cho, Chikusa-ku, Nagoya, 464-8603, Japan



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 HYPER
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

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 1980 1990

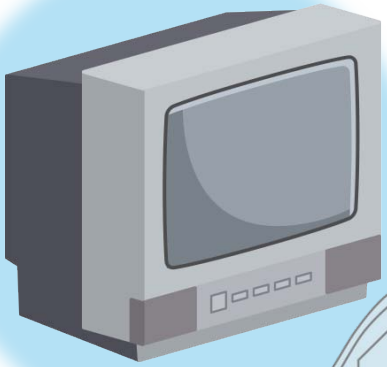
1967
Vapour-grown AlN
Matsushita Research Institute

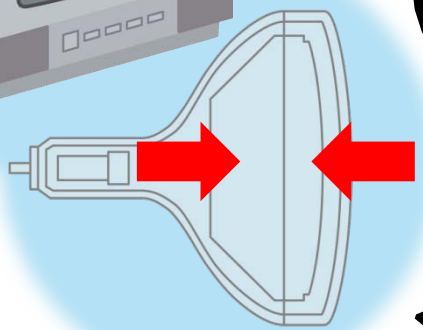
Isamu Akasaki
1992- Meijo Univ.
(Prof. Emeritus Nagoya Univ.)

1981
Nagoya Univ.

1982
Undergraduate

Graduation Research
“Nitride-Based Blue LED”





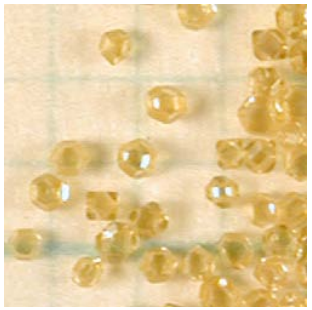
Size of Braun tube is too big !

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℃

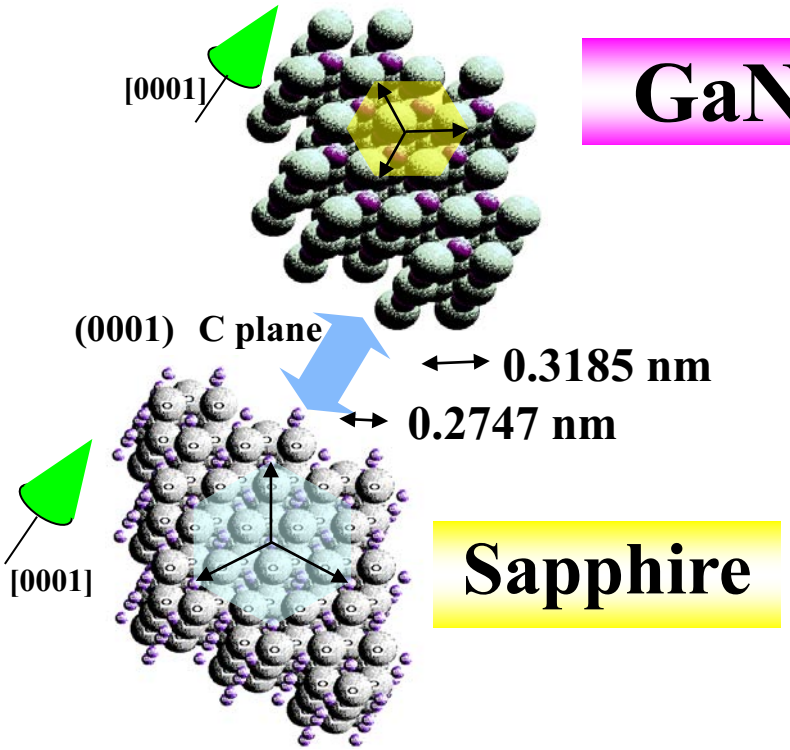


GaN
45,000 atm
2,530℃

50 μm

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

Thin film growth

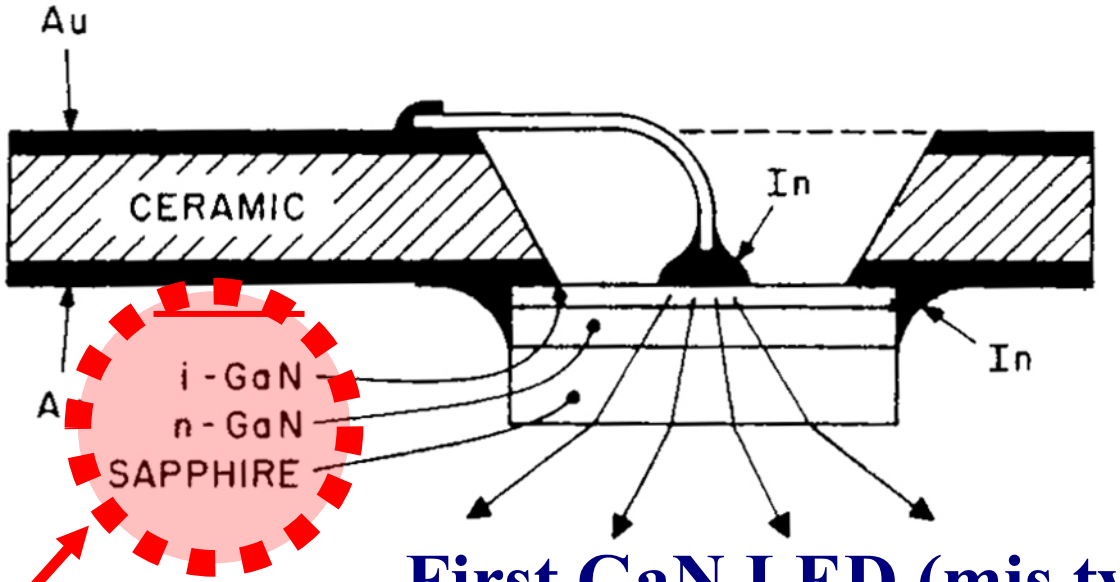


Lattice mismatch

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

In general, lattice mismatch should be <1%.

Why nitride-blue LED was so difficult ?



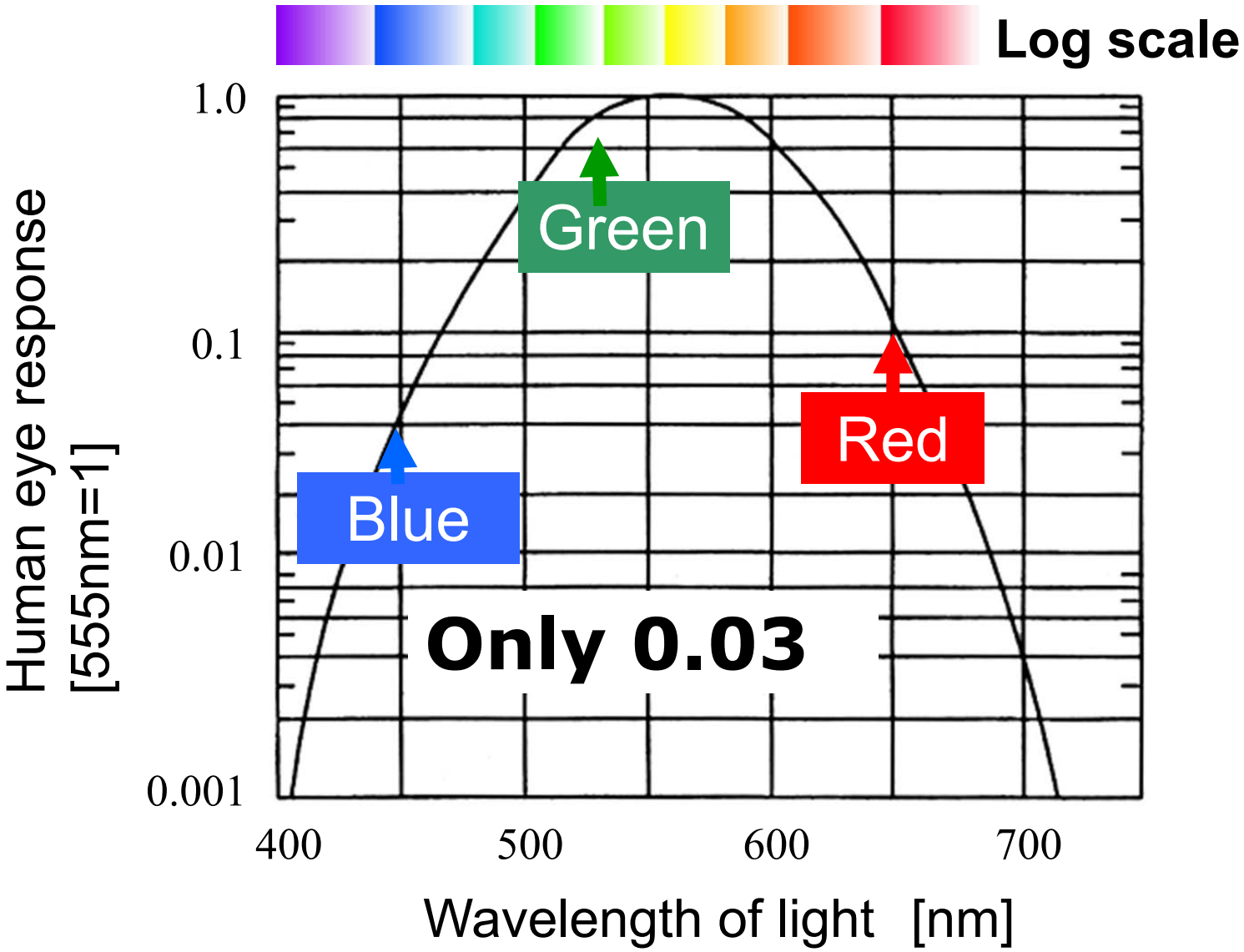
First GaN LED (mis type)

Efficiency : 10^{-5}～3×10^{-4}

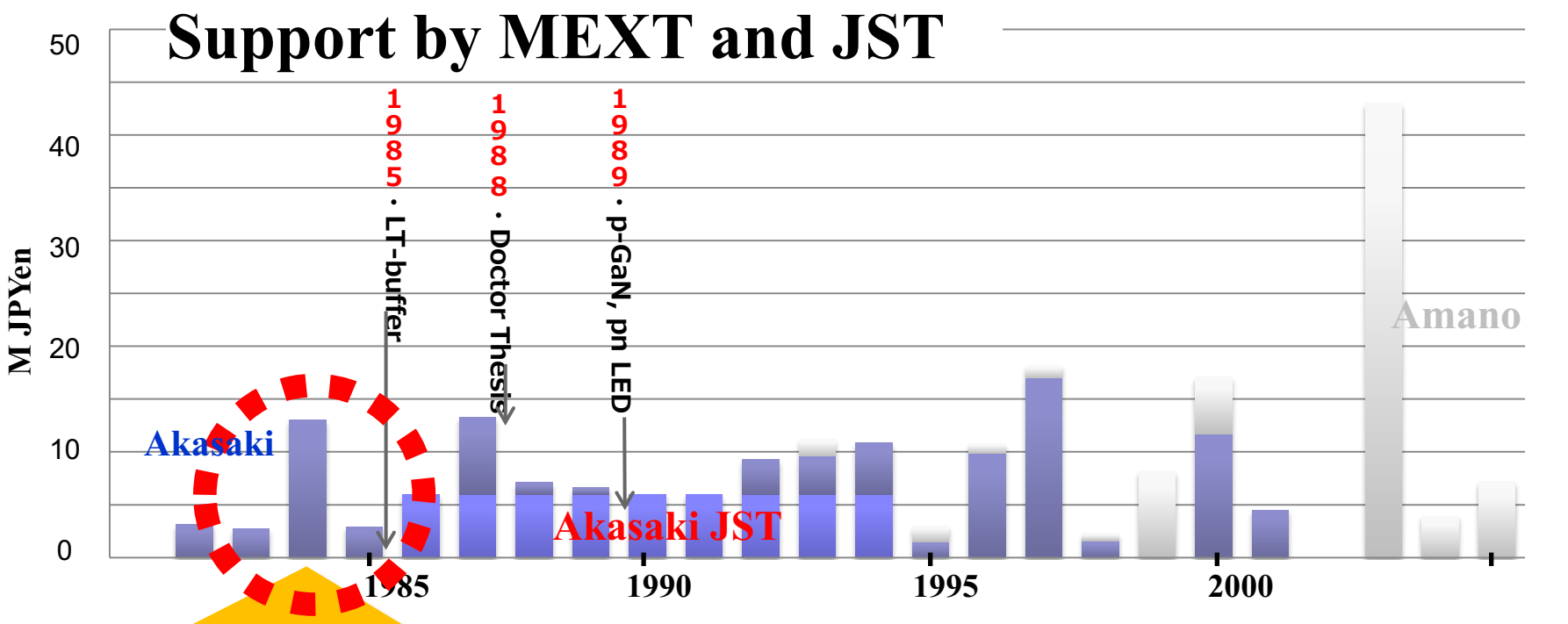
p-GaN could not be grown.

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

Why blue was so difficult ?

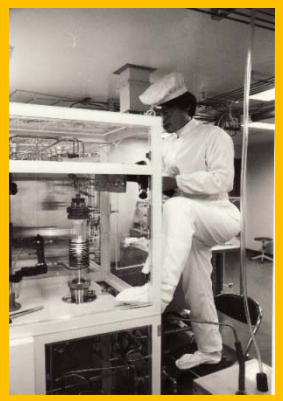


Funding situation of the University in Japan in mid 80's



1US$=115 JPYen

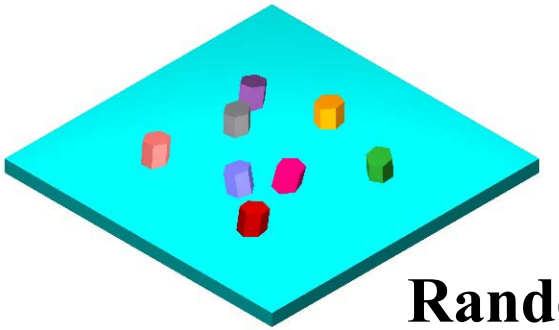
1984



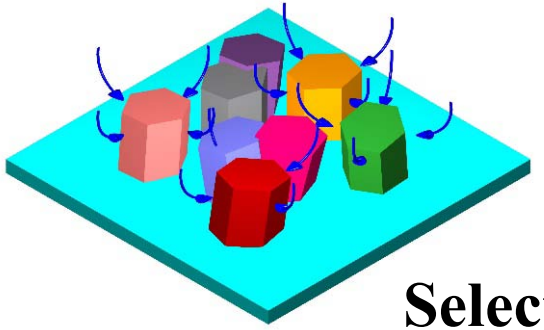
Measuring susceptor temperature by pyrometer

Handmade MOVPE Reactor

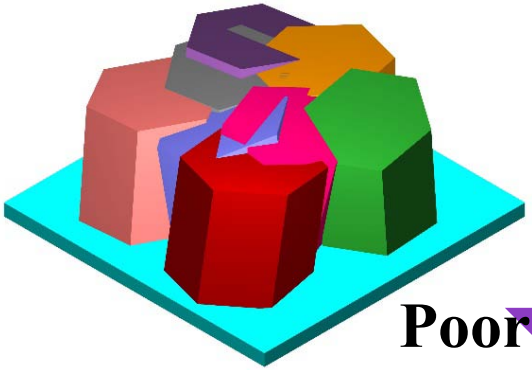
Why it was so difficult to grow high quality GaN?



Random nucleation

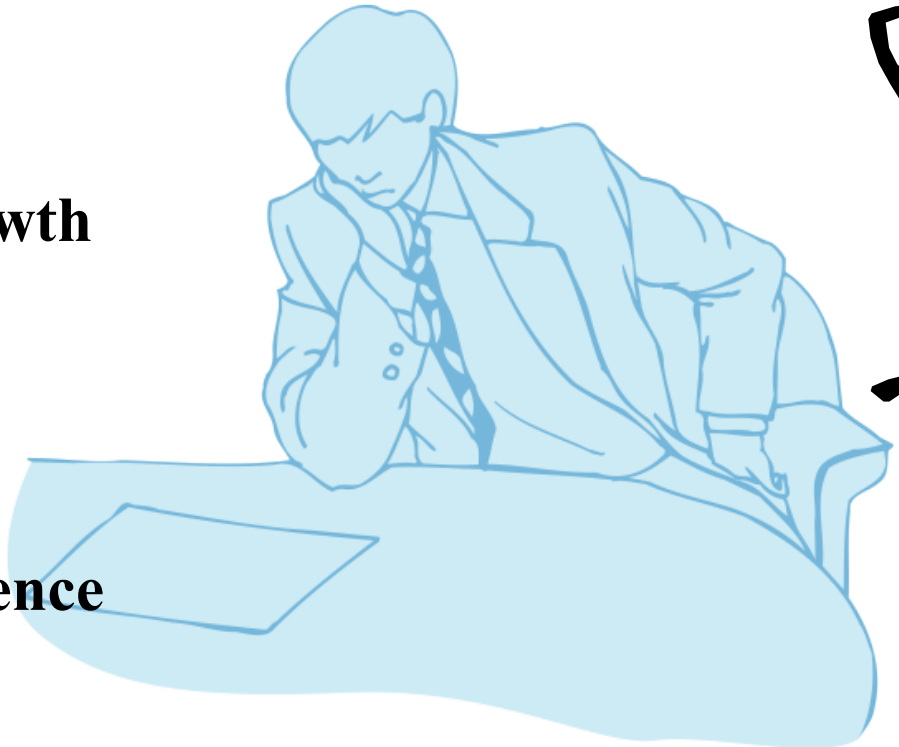


Selective growth

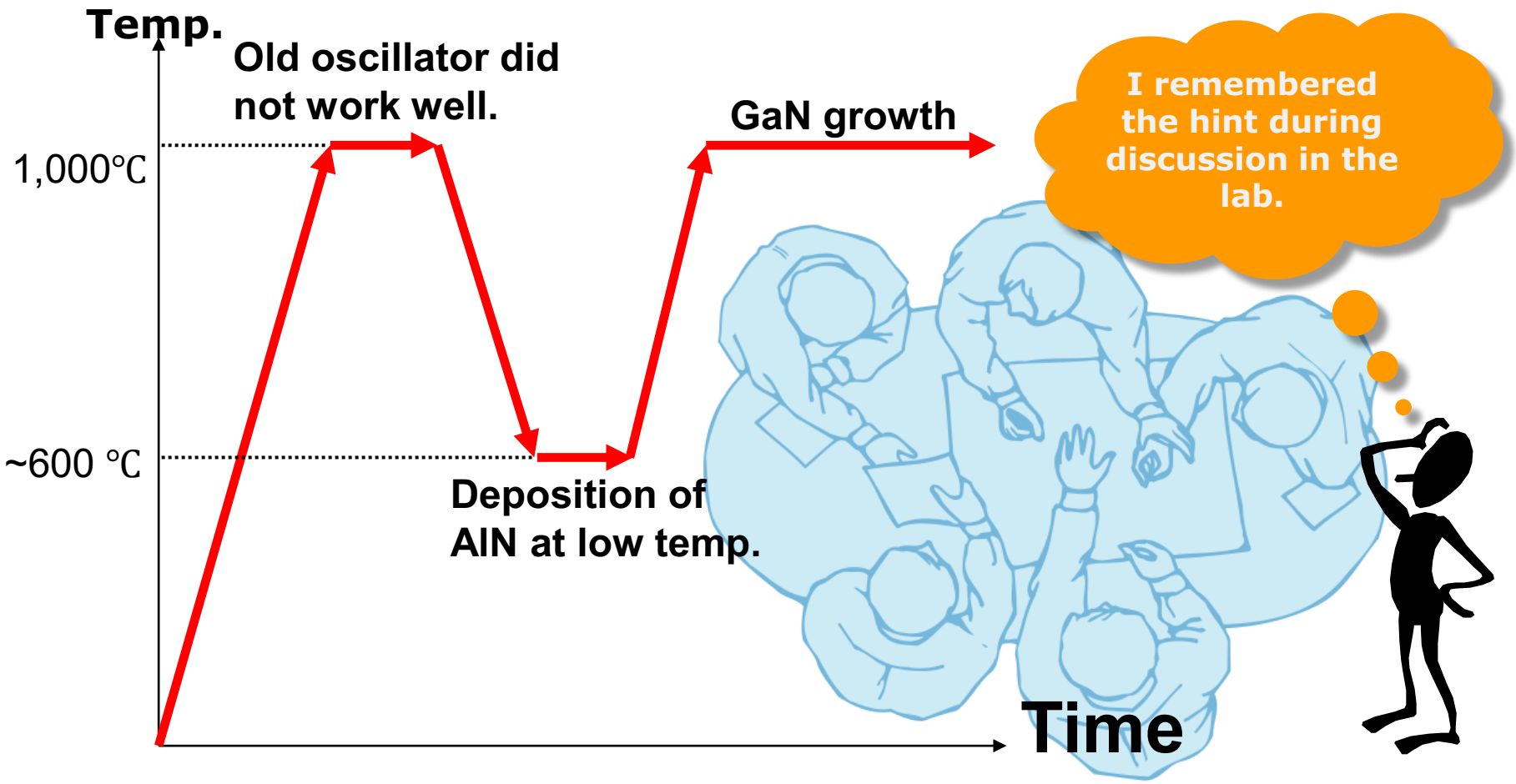


Poor coalescence

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



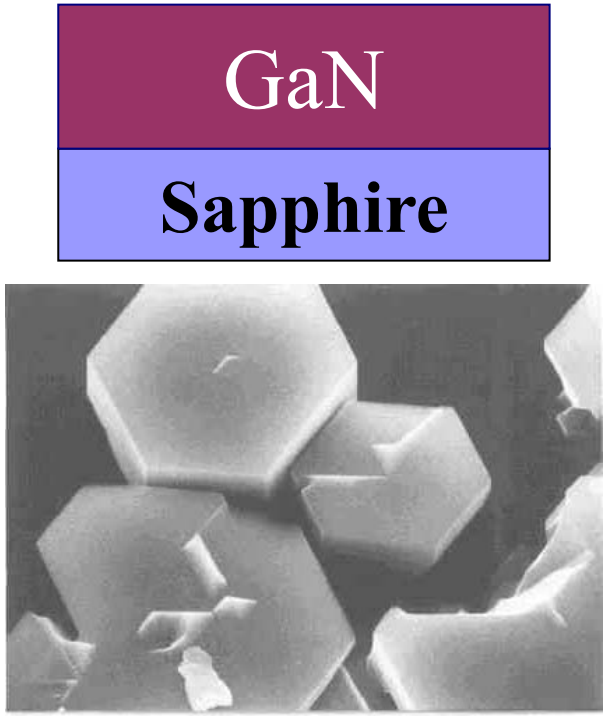
Low temperature deposited buffer layer



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

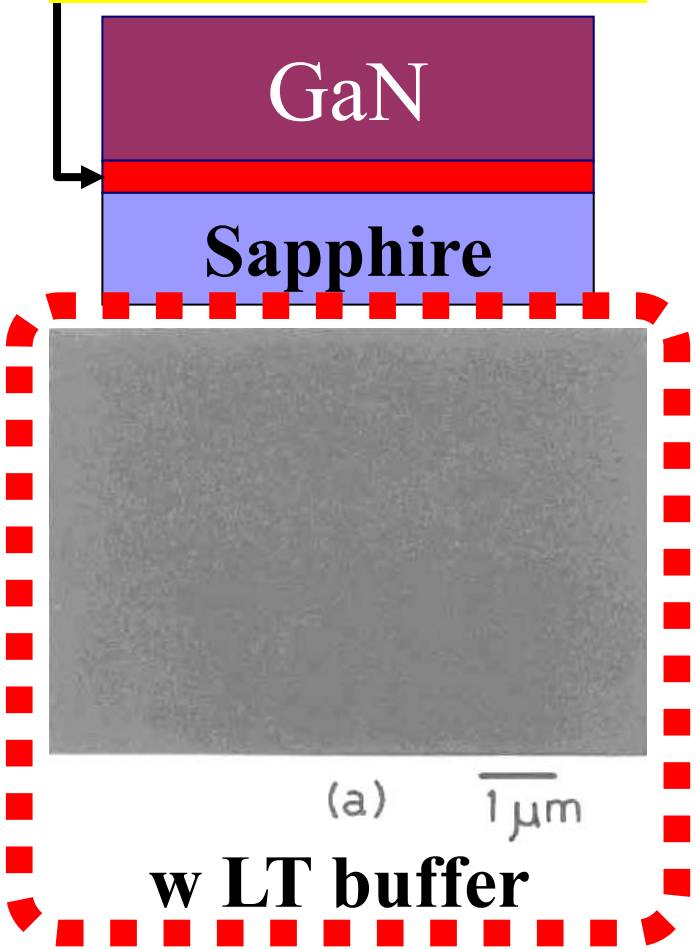
Low temperature deposited buffer layer

Conventional



w/o LT buffer

1985 LT buffer



w LT buffer

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

Low energy electron beam irradiation (LEEBI)

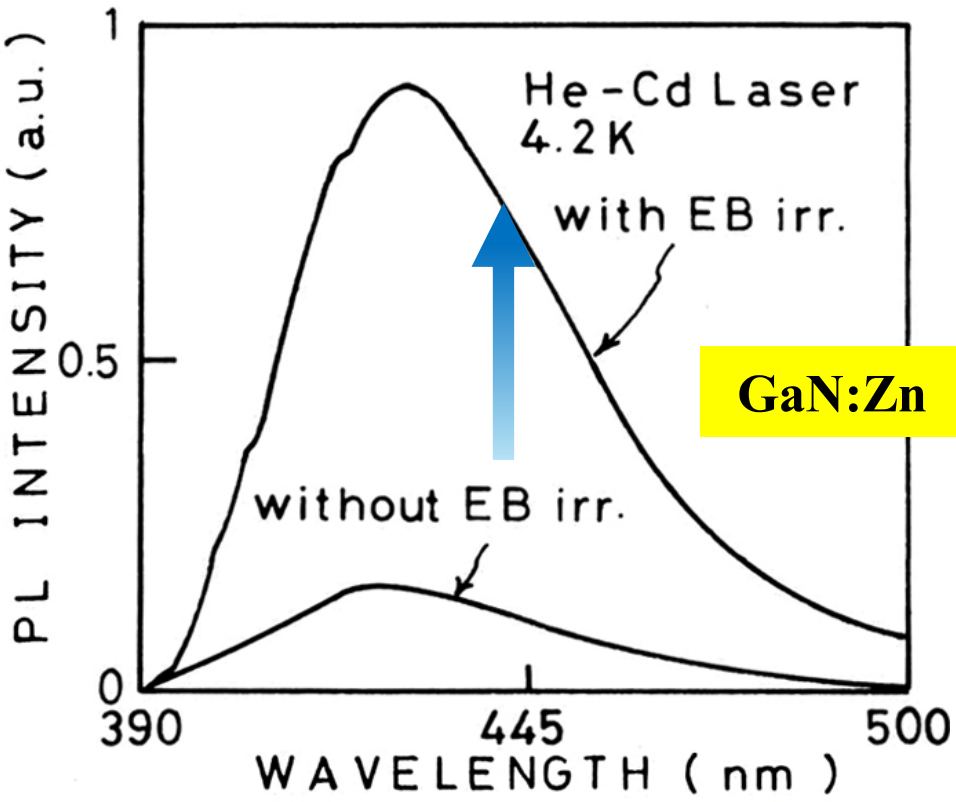


FIGURE 3

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

GaN:Zn

Highly resistive

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

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.

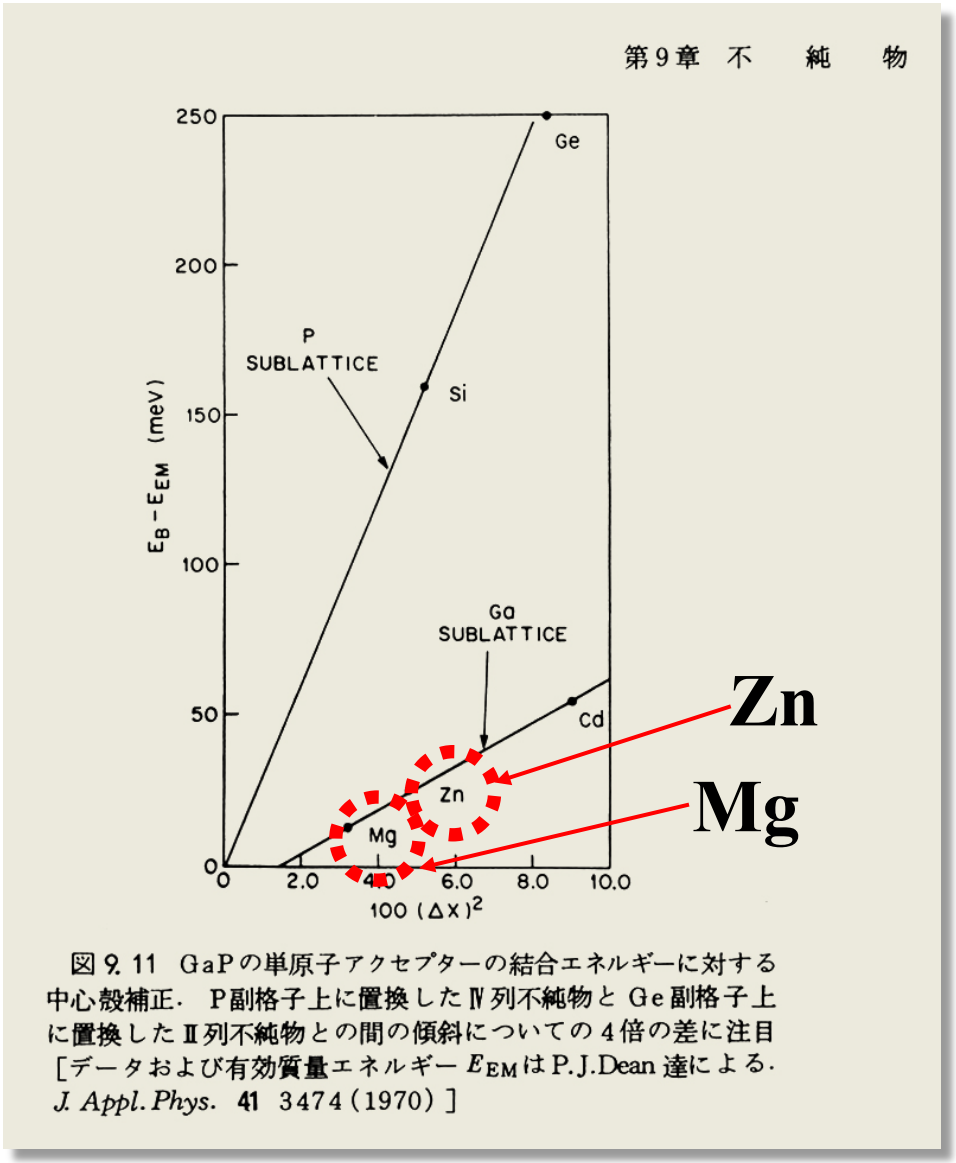


図 9. 11 GaPの単原子アクセプターの結合エネルギーに対する中心殻補正. P副格子上に置換したⅣ列不純物とGe副格子上に置換したⅡ列不純物との間の傾斜についての4倍の差に注目 [データおよび有効質量エネルギー E_{EM} はP.J.Dean達による. *J. Appl. Phys.* **41** 3474 (1970)]

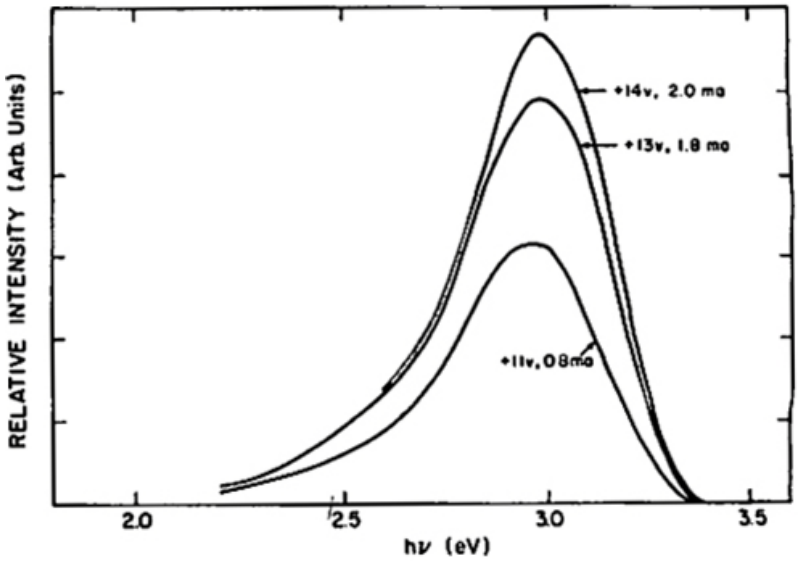
J. Philips, “Bonds and Bands in Semiconductors”

History of Mg

Violet luminescence of Mg-doped GaN

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

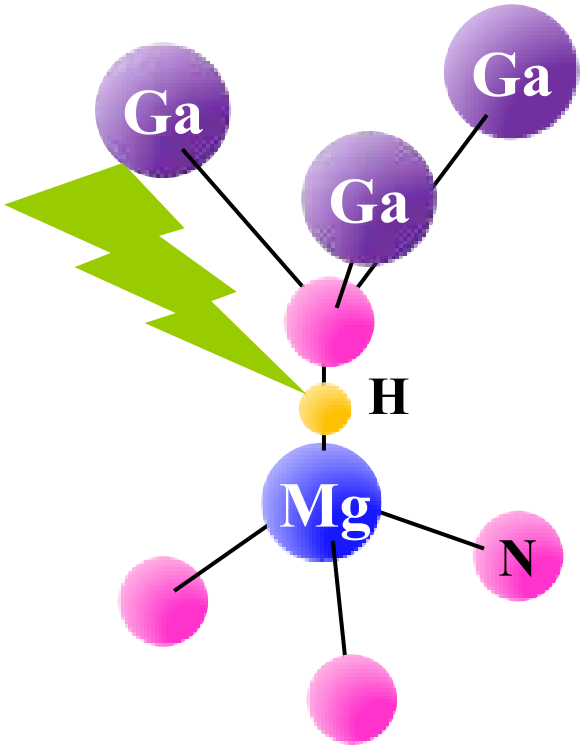
Appl. Phys. Lett., 22, 303 (1973).

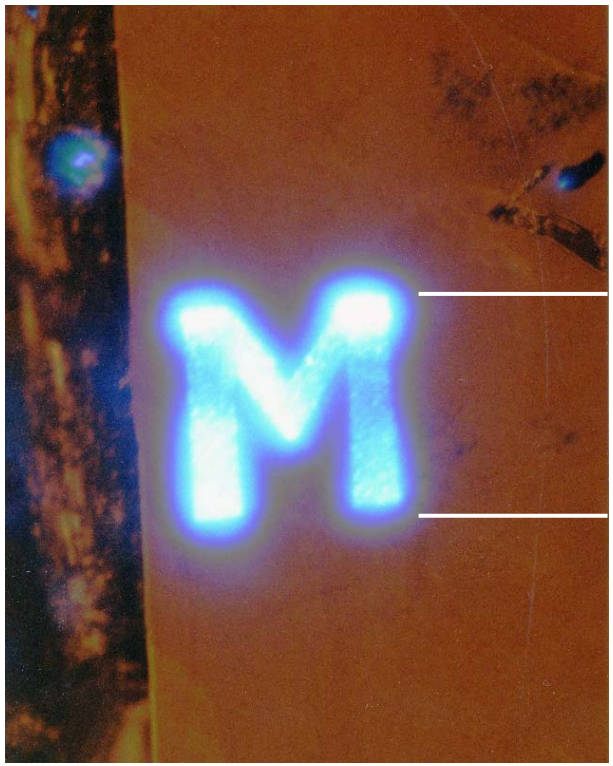


World's first violet LED based on Mg-doped GaN.

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.

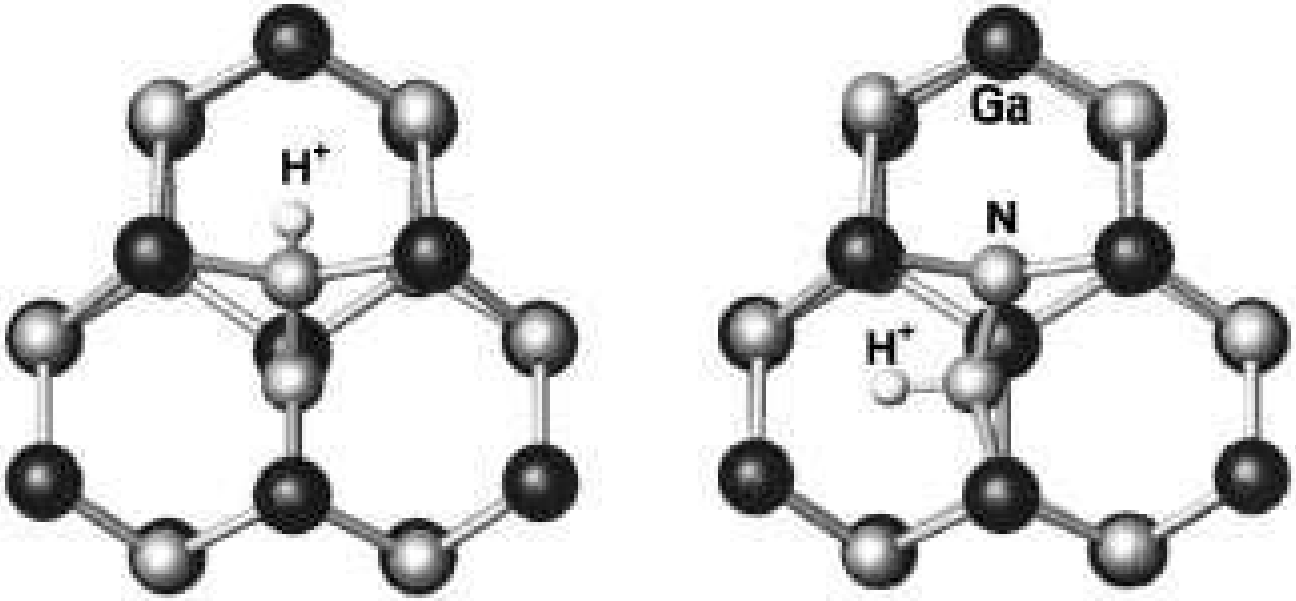
1992 Thermal annealing

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

Mechanism

Hydrogen passivation of acceptor

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

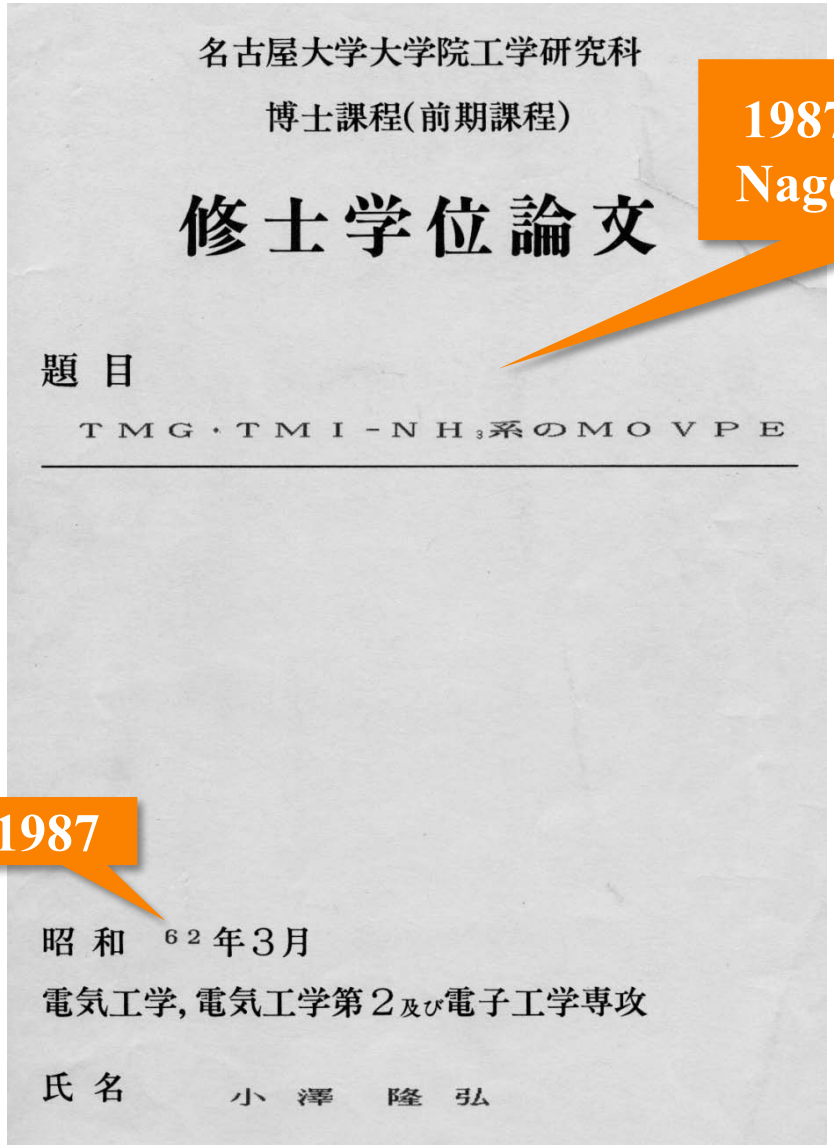


Lattice location of hydrogen in Mg doped GaN

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.

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

題目

TMG・TMI-NH$_3$系のMOVPE

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

1987 Master thesis
Nagoya University

1987

Important finding

1989

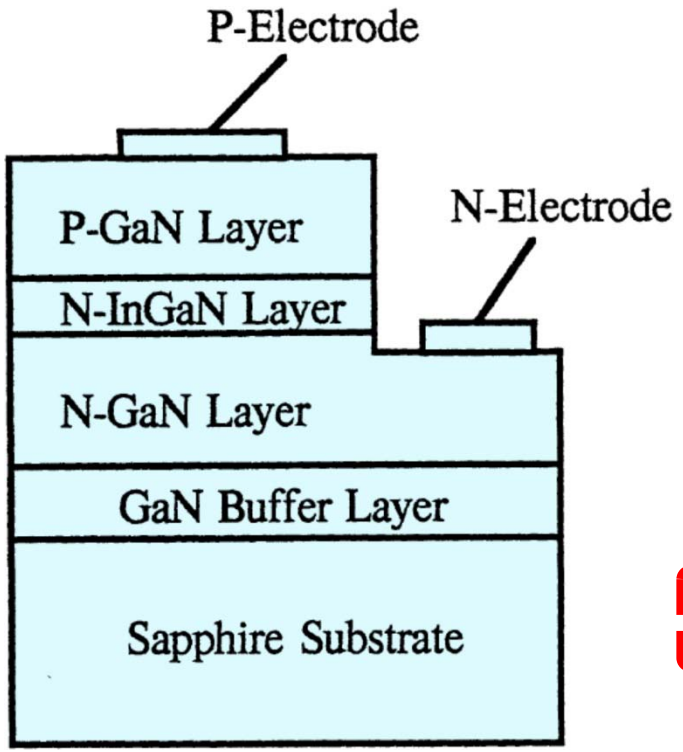
Inst. Phys. Conf. Ser. No 106 : Chapter 3
Paper Presented at Int. Symp. GaAs and Related Compounds, Karuizawa, Japan, 1989

Wide-gap semiconductor (In,Ga)N

T. Matsuoka, *H. Tanaka, T. Sasaki and A. Katsui

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

Company and people who grasped the fortune



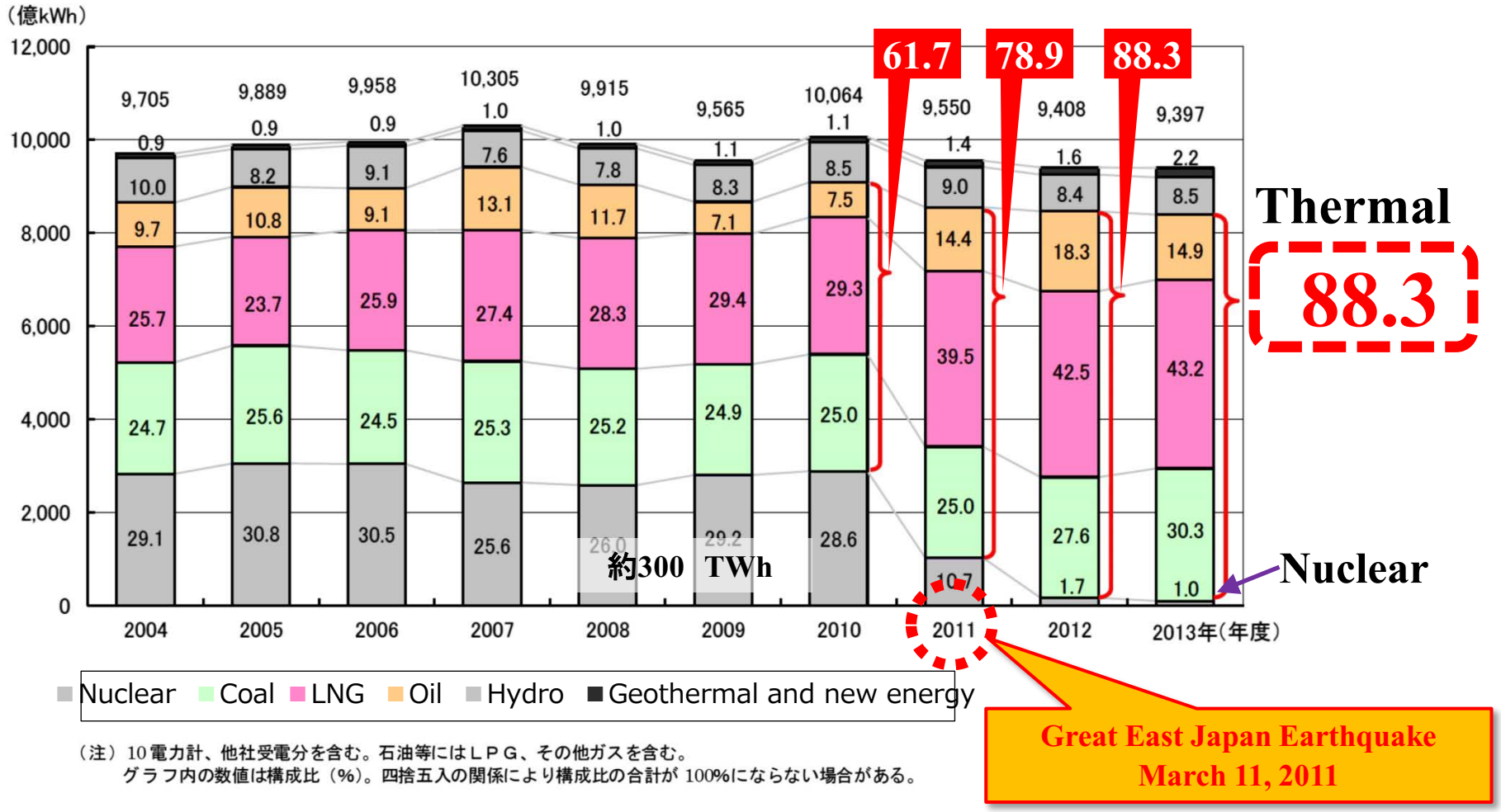
S. Nakamura
et al., JJAP, 32(1993)L8.

1993 World's first commercialization of nitride-LEDs

How InGaN LEDs contribute to energy savings ?

Electricity generation in Japan

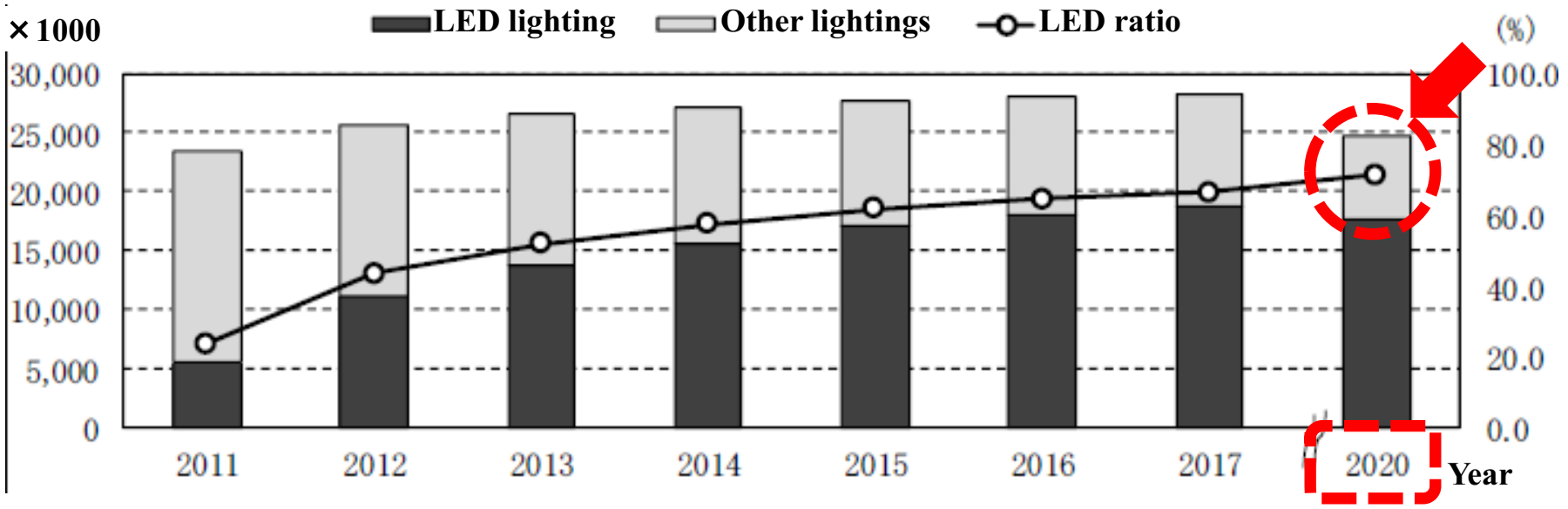
2014.5.23
The Federation of Electric Power Companies of Japan



（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.fepc.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

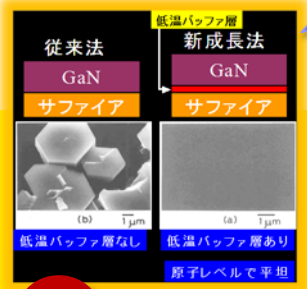
Message to the younger researchers

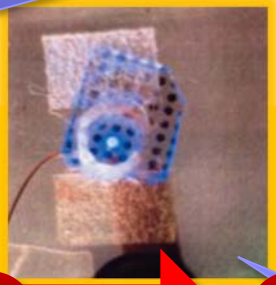
Isamu Akasaki
1981 Nagoya Univ.
1992- Meijo Univ.
(Prof. Emeritus Nagoya Univ.)

Widegap GaN Blue LED

Shuji Nakamiura
(Nichia, now UCSB)

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





1980 — 1985 — 1990 — 1995

Three primary colors

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

1989 JST
1995 Commercialization

Toyoda Gosei

1999 : White LED

Yellow Phosphor

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

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.

Masafumi Hashimoto

UVCR and Nikkiso

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

Acknowledgements

Yoshiko and Tatsuji (Passed away) Amano

Kasumi,
Aya and Mitsuru Amano