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 -

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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

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

1962 N. Holonyak Jr., GaAsP red LD

1971 J. Pankove GaN mis LED

I started nitride research at 1982.

R. Haitz and J. Y. Tsao, phys. stat. sol. (a)208(2011)17
Why I was interested in the blue LEDs?

1970

1980

1990

1967

Vapour-grown AlN
Matsushita Research
Institute

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!

Isamu Akasaki
1992- Meijo Univ.
(Prof. Emeritus Nagoya Univ.)
Why it was so difficult to grow high quality GaN?

In general, lattice mismatch should be <1%.

\[
\frac{0.3185 - 0.2747}{0.2747} \approx +16\%
\]

In general, lattice mismatch should be <1%.

Diamond
52,000 atm
1,200°C

GaN
45,000 atm
2,530°C

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?

![Graph showing human eye response to different wavelengths of light. The x-axis represents wavelength of light in nanometers (nm), and the y-axis represents human eye response on a log scale. The graph shows that only 0.03 (0.03%) of the response is for blue light, making it difficult to achieve a blue color in certain technologies.]
Funding situation of the University in Japan in mid 80’s

Support by MEXT and JST

1984
Handmade MOVPE Reactor

Measuring susceptor temperature by pyrometer

1 US$ = 115 JPYen
Why it was so difficult to grow high quality GaN?

I have tried more than 1,500 times, but I could not get high quality GaN film.
I knew that substrate temperature should be higher than 1200°C for the epitaxial growth of AlN.

Old oscillator did not work well.

Deposition of AlN at low temp.

GaN growth

I remembered the hint during discussion in the lab.

I knew that substrate temperature should be higher than 1200°C for the epitaxial growth of AlN.
Low temperature deposited buffer layer

Conventional

GaN

Sapphire

w/o LT buffer

1985 LT buffer

GaN

Sapphire

w LT buffer

Low energy electron beam irradiation (LEEBI)

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

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

Selection of the dopant
(Zn × MgO)

Highly resistive when it was as grown.

J. Philips, “Bonds and Bands in Semiconductors”
Violet luminescence of Mg-doped GaN

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


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

1992 Thermal annealing


Hydrogen passivation of acceptor
Van Vechten et al., JJAP 31(1992)3662.

Lattice location of hydrogen in Mg doped GaN

W. R. Wampler, S. M. Myers, A. F. Wright, J. C. Barbour, C. H. Seager, and J. Han
Sandia National Laboratories, Albuquerque, New Mexico 87185-1056
修士学位論文

題目

TMG・TMINH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

Good fortune that we missed -InGaN-
Important finding

1989

(a) $V / \text{III} = 16000$
(b) $V / \text{III} = 80000$
(c) $V / \text{III} = 165000$

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

Wide-gap semiconductor (In,Ga)N


NTT OPTO-ELECTRONICS LABORATORIES Tokai, Ibaraki, 319-11 JAPAN
*NTT APPLIED ELECTRONICS LABORATORIES Musashino, Tokyo, 180 JAPAN
Company and people who grasped the fortune

1993 World’s first commercialization of nitride-LEDs

How InGaN LEDs contribute to energy savings?

Electricity generation in Japan

Great East Japan Earthquake
March 11, 2011

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

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

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

Toyoda Gosei

1999 : White LED

Three primary colors

1980
1985
1990
1995

© 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,
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**Toyota Central R&D Labs.**

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Kasumi,
Aya and Mitsuru Amano