The 2009 Kyoto Prize Workshop in Advanced Technology

Symposium

"Nitride Semiconductors and Their Device Applications: Current Status and Future Prospects"

Laureate: Dr. Isamu Akasaki
[University Professor, Nagoya University
Professor, Meijo University]

13:00 - 17:25, November 12, 2009 (Thu.)
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13:00 **Opening Address and Introduction of Laureate**
Hiroyuki Sakaki

Laureate Lecture
Isamu Akasaki (the Laureate in Advanced Technology)
"Dramatic Improvement of GaN Crystal Quality and Realization of p-n Junction Blue LEDs"

Lecture
Koichi Ota (Managing Director (R&D Center, Optoelectronics Sales Div.), Toyota Gosei, Co., Ltd.)
" Nitride semiconductor LEDs"

Lecture
Masao Ikeda (R&D Director and Chief Distinguished Engineer, Advanced Materials Laboratories, Sony Corporation)
" Nitride semiconductor LDs"

Intermission

Lecture
Fumio Hasegawa (Professor Emeritus, University of Tsukuba)
"Nitride semiconductor high-speed and power devices"

Lecture
Yasuhiko Arakawa (Professor, Institute of Industrial Science, The University of Tokyo)
"Nitride semiconductor nanostructures"

Joint Session "Development of nitride semiconductor"
Akira Usui (Executive Officer, R&D Division, Furukawa Co.,Ltd.)
"Reduction of defects in nitride semiconductors"
Katsumi Kishino (Professor, Faculty of Science and Engineering, Sophia University)
"Nitride semiconductor nanocolumns"
Yoichi Kawakami (Professor, Graduate School of Engineering, Kyoto University)
"Optical processes in nonpolar and semipolar nitride semiconductors"
Hiroshi Amano (Professor, Faculty of Science and Engineering, Meijo University)
"Development of group III nitride semiconductors for light emitting, photodetector and solar cells covering infrared to UV region"
Yasushi Nanishi (rofessor, Faculty of Science and Engineering, Ritsumeikan University and Professor, Department of Materials Science and Engineering, Seoul National University)
"Advancement of Indium Nitride Based Semiconductors"

17:25 **Closing**

Abstract of the Laureate Lecture

Dr. Isamu Akasaki
University Professor, Nagoya University
Professor, Meijo University

Dramatic Improvement of GaN Crystal Quality and Realization of p-n Junction Blue LEDs

The extreme difficulties both in growing high-quality GaN single crystal and achieving p-type conduction prevented the development of high-performance blue light-emitting devices for many years. In 1974 I began to work on GaN, and in 1978, I recognized its great potential when I found tiny yet high-quality crystallites embedded in larger HVPE-grown crystals containing cracks and pits.

In order to achieve this kind of quality over an entire wafer, I decided to return to basics, i.e., the fundamentals of crystal growth, and in 1979 to adopt MOVPE as the optimal crystal growth method for GaN.

Since 1981, with the most generous cooperation of graduate students and co-researchers at Nagoya University, I began experimenting with the MOVPE growth of GaN. After much trial and error, we could finally obtain fairly uniform GaN films on sapphire substrates by suppressing adduct formation by means of mixing organometallic compounds with ammonia just before the reactor inlet, and by feeding the source gases through a delivery tube to a slanted substrate at a high velocity.

Furthermore, to reduce the interfacial free energy due to the large lattice-mismatch between GaN and sapphire, we developed a “low-temperature-deposited buffer layer technique”, which was based on the idea of making the growth conditions similar to those of homoepitaxy. In 1985, we succeeded in growing the world’s first extremely high-quality GaN single crystal using this technique. The GaN crystal was quite transparent, colorless, and had a mirror surface. Simultaneously with the improvement in crystallinity, the electrical and luminescence properties were dramatically enhanced.

Despite repeated attempts at Zn-doping of high-quality GaN films, with residual donor densities of less than 1015 cm-3, no p-type conduction could be achieved. Then, in 1987, Hiroshi Amano discovered that the intensity of Zn-related luminescence greatly increased, with no change in spectral shape, when the Zn-doped high-quality GaN films were subjected to low-energy electron beam irradiation (LEEBI). We also realized in 1988 that Mg was a potentially shallower acceptor than Zn, since its electronegativity is intermediate between those of Zn and Ga.

Finally, in 1989, we achieved p-type conduction by LEEBI treatment of high-quality GaN doped with Mg using CP2Mg. Immediately, we realized the world’s first GaN p-n junction blue/UV LED with encouraging I-V characteristics.

Moreover, we achieved conductivity control of n-type nitrides and stimulated emission from GaN at room temperature, and verified quantum effects in the nitride system.

In this way, we developed all the essential technologies for realizing GaN-based p-n junction photonic and electronic devices.

Abstracts

Koichi Ota

Managing Director of the Board (R&D Center, Optoelectronics Sales Div.), TOYODA GOSEI CO., LTD.

Nitride semiconductor LEDs

Blue LEDs were not considered to be developed during the 20th Century.
Prof. Akasaki aggressively spent his life for developing GaN which is a material suitable for Blue LEDs.
As a result, the following all fundamental technologies for Blue LEDs (used for White converted LEDs) were established first in the world.

1) Crystallization of high quality GaN
2) n-type GaN
3) p-type GaN

These LEDs are used for large size full screen displays, backlights of cell phones and notebook PCs, and recently penetrating into LCD TVs and light sources of general lighting. Its market size is huge and unpredictable.
Toyoda Gosei started the R and D of Blue LEDs in 1986 under Prof. Akasaki's supervision and commercialized Blue LEDs.
In this report, the history of Blue LED development is reviewed, and its technologies progress and applications including the future technologies are introduced.

Masao Ikeda

R&D Director and Chief Distinguished Engineer, Advanced Materials Laboratories, Sony Corporation

Nitride semiconductor LDs

Stimulated by the fact that the GaN-based laser diode (LD) was successfully realized using breakthroughs brought by Prof. Akasaki et al., we changed our direction of developing short-wavelength LD based on II-VI materials for use in next-generation optical disk systems, toward development based on nitride materials. Thanks to the rigid nature of GaN-based materials, such as stable threading dislocations in the active layers which are never multiplied by current injection, and a high critical optical power density for catastrophic optical damage of laser facets, the development of reliable and high-power LDs progressed quite satisfactorily, resulting in the successful commercialization in Blu-ray Disc, PS3, and so on. Recently in collaboration with Tohoku University, we started to investigate pico-second super high-power lasers as an attempt to pursue the potential performance of GaN-based LD and expand applications. The superior potential of GaN-based materials has already been demonstrated by 12 W peak-power under gain-switching operation, which was one order of magnitude higher than the power reported for other material systems. In this talk therefore, I would like to present our recent results of pico-second super high-power LDs based on GaN-based materials.

Abstracts

Fumio Hasegawa
Professor Emeritus, University of Tsukuba

Nitride semiconductor high-speed and power devices
--- Present status and future prospect of AlGaN/GaN HFETs ---

Compound semiconductor electron devices have to always compete with Si devices in cost as well as in performance, differently from light emitting devices. Even if output power and efficiency (performance) is 1.5 times better than those of Si devices, compound semiconductor electron devices can not be sold in twice price.

There are two applications for nitride electron devices; microwave devices and power switching devices. The former is already used for power amplifiers of meteorological radars and satellite communications as replacement of klystrons and traveling wave tubes. They are expensive, lower reliable than semiconductor devices and need a high voltage power supply, therefore, expensive nitride devices can be used. The biggest potential market of the power switching device is those for hybrid and electric vehicles. Normally off operation is inevitable for the switching device for vehicles. Several structures have been proposed and demonstrated, but the performance is not enough yet. A structure with an essential normally off mechanism should be developed even if it needs a complicated structure with a difficult fabrication process.

Yasuhiko Arakawa
Professor, Institute of Industrial Science, The University of Tokyo

Nitride semiconductor nanostructures

The nitride semiconductor science established by the pioneering achievement of Dr. Isamu Akasaki has emerged in the last decade as innovative technologies for blue light-emitting diodes, lasers and FETs which are indispensable in future IT societies. On the other hand, the concept of quantum dots proposed in 1982 has brought up unique features of artificial atoms, leading to a wide variety of experimental investigations into semiconductor physics and device applications. In particular, a remarkable progress of InAs-based quantum dot technology has resulted in commercialization of the quantum dot lasers in the quite near future. In this presentation, we overview recent advances in GaN-based nanostructures with emphasis on physics, growth, and device applications of quantum dots and nanowires. Outlook and issues of research fields of GaN-based nanostructures are also addressed.

Abstracts

Akira Usui
Executive Officer, R&D Division, Furukawa Co., Ltd.

Reduction of defects in nitride semiconductors

The first report on semiconductor GaN crystal growth was published in 1969, where the growth was carried out by HVPE (hydride vapor phase epitaxy) method on a sapphire substrate. However, the crystallinity was insufficient because the large island growth was dominant on the substrate. Important breakthrough was in a low-temperature buffer layer technique proposed by Dr. Akasaki et al, which becomes a standard process to grow nitrides materials on foreign substrates. However, in order to improve device performances, further reduction of dislocation density was needed. The lateral overgrowth method was proposed to satisfy with such requirement. In this technique, the generation of dislocations in the overgrown layer on the mask was suppressed and threading dislocations were largely reduced by the bending effect due to facet planes appeared on the side walls of selective-area growth clusters. In this talk, the reduction of defects in nitride semiconductors using above techniques will be discussed by focusing on the preparation of GaN crystal by HVPE.

Katsumi Kishino
Professor, Faculty of Science and Engineering, Sophia University

Nitride Semiconductor Nanocolumns

Nanodevices have attracted considerable attention from researchers. Nitride semiconductor nanocolumns are one-dimensional nanocrystals of typically 20-300nm diameter and 2□m height. Using their dislocation-free property and high light extraction efficiency, the fabrication of high-efficiency nano-emitters producing green to red emission is highly expected. Initially, GaInN-based nanocolumns were grown through the self-assembling technique, but this introduced fluctuations in the size and position of nanocolumns, bringing about multicolor emissions. Thus we have developed a selective-area-growth technique to control the nanocolumn size and position, and a uniform array of nanocolumns was successfully fabricated. The photoluminescence emission from the InGaN quantum well was then evaluated, and we observed that the emission color changed monotonically from blue, green to red. This phenomenon indicates the possibility of realizing full-color nanodevices, such as three-primary-color nanoemitters, nanopixel devices and so forth, using GaInN-based nanocolumns. A two-dimensional periodic arrangement of nanocolumns generates strong light confinement at a specific wavelength, by which the first stimulated emission from GaInN-based nanocolumns was observed.

Abstracts

Yoichi Kawakami
Professor, Graduate School of Engineering, Kyoto University

Optical processes in nonpolar and semipolar nitride semiconductors

Twenty years has passed since the first achievement of the pn-conductivity-control in GaN. Thereafter, the development of light emitting diodes (LEDs) and laser diodes (LDs) has been made day by day, reaching to the realization of highly efficient light emitting devices based on InGaN, covering from near ultraviolet to blue spectral region. However, the problem still exists, where the sufficient efficiency cannot be obtained in the wavelength longer than blue-green range if In compositions are further increased. This mechanism is now understood as a result of huge internal electric fields induced by piezo-electric polarization in In-rich InGaN quantum wells grown on polar GaN (c-plane in hexagonal phase). Accordingly, this problem has led to the intensive research, where the fabrication and basic study have been performed in the InGaN/GaN hetero-structures grown on nonpolar substrates (tilted 90° with respect to c-plane), and on semipolar ones (tilted in the range of 0° to 90° with respect to c-plane). I will introduce the key developments and the future prospects in nonpolar and semipolar nitride materials and devices.

Hiroshi Amano
Professor, Faculty of Science and Engineering, Meijo University

Development of group III nitride semiconductors for light emitting, photodetector and solar cells covering infrared to UV region

High performance UV to green LEDs, white LED composed of blue LED and yellow phosphors, and violet laser diode have been commercialized using GaN-based AlGaInN semiconductors. UV and green laser diodes have also been developed by this material system. Potential of this material should not be limited from UV to green region. It is theoretically possible to fabricate infrared devices using InN and VUV devices using AlN. The highest efficiency solar cell is also possible by using tandem structure of this material system. However, due to the lack of suitable growth technique for In-rich GaInN and Al-rich AlGaN, we are unable to fabricate such novel devices. Recently, we developed new growth technology for In-rich GaInN and Al-rich AlGaN, by which we can grow high quality GaInN and AlGaN. In this presentation, new growth technology for group III nitride semiconductors having the whole compositional range will be shown.

Abstracts

Yasushi Nanishi
Professor, College of Science and Engineering, Ritsumeikan University
Professor, Department of Materials Science and Engineering, Seoul National University

Advancement of Indium Nitride Based Semiconductors

Bandgap energy of Indium Nitride (InN) has believed to be 1.9 eV for more than 30 years. Seven years have passed since narrow bandgap energy of around 0.7 eV was reported and this new value is well recognized these days after extensive discussions on this subject. Not only band gap energy, many physical parameters like effective mass, mobility and peak velocity are all revised. Owing to these new findings, new potential applications of nitride semiconductors and alloys like very high efficiency solar cells, wide spectrum range light emitters and sensors from deep UV to IR, high frequency electronic devices up to Terahertz operation are opened up. Several serious issues like reproducible and high quality crystal growth, high density residual carries, p-type doping and high density surface accumulated carriers should be resolved, however, before InN and related alloys are successfully applied to actual devices. Review on these recent advancements of InN and related alloys will be presented in this talk.