Interview

An interview with Professor Isamu Akasaki of Meijo University, pioneer in the field of semiconducting GaN (gallium nitride) and related devices.

Professor Akasaki was born in Kagoshima, Kyushu. He received his bachelor's degree from Kyoto University in 1952 and his doctoral degree in Electronic Engineering in 1964 from Nagoya University. In 1952, he joined *Kobe Kogyo Corporation* (now Fujitsu Ltd.) and then moved to Nagoya University, where he held the positions of research associate and assistant professor before being appointed an associate professor in 1964.

From 1964 to 1981, Professor Akasaki was Head of the Fundamental Research Laboratory and General Manager of the Semiconductor Department at Matsushita Research Institute, Tokyo, until he became a professor at Nagoya University in 1981. Since 1992, Professor Akasaki has been both a professor emeritus at Nagoya University and a professor in the Department of Electrical and Electronic Engineering at Meijo University.

Professor Akasaki has authored and co-authored in total more than 300 technical papers and contributed to 24 books. In addition to being a member of several advisory boards to the Japanese government, he has also chaired numerous international conferences and technical meetings.

The Japanese Association for Crystal Growth (JACG) Prize was awarded to Professor Akasaki in 1989 "for his distinguished contributions to the development of hetero-epitaxial growth of nitrides on highly mismatched substrates". Just two years later, in 1991, he received the Chu-nichi Cultural Award in recognition of "his pioneering work in developing wide band-gap column III nitrides and the first GaN *p-n* junction blue LED (light-emitting diode)". Then, in 1994, he was awarded first the Optoelectronics Conference Special Award for his "outstanding contribution to the basic research and development of high radiance GaN blue light-emitting diodes", and then the JACG Technological Contribution Award in commemoration of JACG's 20th Anniversary, for outstanding achievements concerned with the epitaxial growth of compound semiconductor crystals".

In 1995, Professor Akasaki went on to receive both the International Symposium on Compound Semiconductors Award and the Heinrich Welker Gold Medal "for his pioneering and outstanding contributions in the field of III-V nitride compound semiconductor research" and, in 1996, the IEEE/LEOS Engineering Achievement Award "for the technology breakthrough of making p-type gallium nitride, and demonstrating very bright blue light-emitting diodes, which is expected to have a major impact in the display and other optoelectronic industries". Most recently, Emperor Akihito honoured Professor Akasaki in November 1997 with the coveted Medal with Purple Ribbon for his achievements in science, education and culture.

In July 1998, Professor Akasaki will be awarded the Laudise Prize by The International Organisation for Crystal Growth for "significant contributions in technological aspects of crystal growth" at the 12th International Conference on Crystal Growth.

Furthermore, in December 1998, Professor Akasaki will be presented the IEEE Jack A. Morton Award at the IEDM for "contributions in the field of group III nitride materials and devices" and the British Rank Prize for his great contributions to optoelectronics.

It could be said that the semiconductor industry is going through a "blue period". This "blue period" is one of great excitement and expectation for researchers, businesses and society as a whole. The use of semiconducting GaN in the fabrication of LEDs and blue light-emitting lasers has at last enabled us to see our way to realising full-colour displays, highly energy efficient traffic lights, ultra high-density optical storage systems. And "white light" from LEDs might even replace Edison's incandescent filament light bulb! (An excellent review of semiconducting nitrides can be found in *Nature*, Vol. 386, 27 March 1997, p. 351.)

In this issue of OBI Professor Akasaki has generously agreed to share with us his experiences and personal insights into the very earliest stages of his pioneering work on GaN, the material at the heart of the "blue period".

OBI: When did you first start research on GaN?

Professor Akasaki: I first started working on GaN in 1974, thinking that one day there would be a need for short wavelength optical devices. Having thoroughly surveyed a wide variety of materials, it seemed to me that GaN looked particularly promising; I was also particularly inspired by the work of Professor Pankove on LEDs (see table). I was in industry at the time and well knew that my company was unlikely to fully fund such risky research. That was one of the reasons why I decided to submit my research proposal on "Blue Colour Light Emitting Devices" to the Ministry of International Trade and Industry (MITI). I had proposed using gas-source molecular beam epitaxy (MBE), with metallic gallium and ammonia as the source materials.

The committee tried to tell me that a system using ammonia in an ultra-high vacu-

Recent history of nitride research activities upto 1996

Date	Event	Author	Reference
1969	GaN by hydride vapour phase epitaxy	Maruska and Tietjen	Appl. Phys. Lett. 15, 327 (1969)
1971	Metal-insulator-semiconductor LEDs	Pankove et al	RCA Rev. 32, 383 (1971)
	GaN by MOCVD	Manasevit et al	J. Electrochem. Soc. 118, 1864 (1971)
	Ultraviolet stimulated emission at 2 K	Dingle et al	Appl. Phys. Lett. 19, 5 (1971)
	Study of luminescence	Pankove and Lampert	Phys. Rev. Lett. 33, 361, (1974)
1974	GaN by sublimation	Matsumoto and Aoki	Jpn J. Appl. Phys 13, 1804 (1974)
	GaN by MBE (Ga + NH_3)	Akasaki et.al	MITI report in Japanese only (1974) Ind. Sci. Technol. 17, 48 (1976)
1975	AlN by MBE (Al + NH_3)	Yoshida et al	Appl. Phys, Lett. 26, 461 (1975)
1982	Synthesis (high pressure)	Karpinski et al	J. Cryst. Growth 56, 77 (1982)
1983	AlN intermediate layer (MBE)	Yoshida et al	Appl. Phys, Lett. 42, 427 (1983)
1986	Specular films using AlN buffer layer /(high μ) (MOCVD)	Amano and Akasaki	Appl, Phys. Lett, 48, 353 (1986)
1989	*p*-type doping with Mg and LEEBI	Amano et al.	Jpn. J. Appl, Phys. 28, L2112 (1989)
	GaN *p-n* Junction LED	Amano and Akasaki	Jpn. J. Appl, Phys. 28, L2112 (1989)
	InGaN epitaxy (XRRC = 100 arcmin)	Nagamoto et al	Jpn. J. Appl, Phys. 28, L1334 (1989)
1990	Conductivity control of *n*-type nitrides	Amano and Akasaki	Mat. Res. Soc. EA-21, 165, (1990)
	UV stimulated emission at room temperature	Amano et.al	Jpn. J. Appl. Phys. 29, L205 (1990)
1991	GaN buffer layer by MOCVD	Nakamura	Jpn. J. Appl. Phys. 30, L1705 (1991)
1992	Mg activation by thermal annealing	Nakamura et al	Jpn. J. Appl. PhysL 31, L139 (1992)
	High-brightness AlGaN UV/blue LEDs (1.5%)	Akasaki et al	Inst. Phys, Conf .Ser. vol.129 (1992)
	InGaN epitaxy (XRRC = 5 arcmin)	Nakamura et al	Jpn. J. Appl. Phys. 31, Ll456 (1992)
1993	InGaN MQW structure	Nakamura et al	J. Appl. Phys, 74. 391 1 (1993)
1994	InGaN/AIGaN DH blue LEDs (1 cd)	Nakamura et al	Appl. Phys. Lett. 64, 1687 (1994)
	InGaN/AlGaN DH blue-green LEDs (2 cd)	Nakamura et al.	J. Appl, Phys. 76, 8189 (1994)
	High temperature hetero-bipolar transistor	Pankove et.al	Proc. IEDM, 389, (1994)
1995	InGaN SQW green LEDs (10 cd)	Nakamura et al	Jpn. J. Appl. Phys. 34, L1332 (1995)
	Stimulated emission (from GaInN SQW) by current injection	Akasaki et.al	Jpn. J. Appl. Phys. 34, L1517 (1995)
1996	Blue laser diode, pulsed operation	Nakamura et al	Jpn. J. Appl. Phys. 35, L74 (1996)
	Shortest wavelength laser diode	Akasaki et al	Elect. Lett. 32, 1105 (1996)
	Blue laser diode, pulsed operation	Itaya et. al	Jpn. J. Appl. Phys. 35. L1315 (1996)
	Blue laser diode, CW operation	Nakamura et.al	Mat. Res. Soc. 449, 1135 (1996)

Contents based on information provided by Professor Akasaki and *Nature* Vol. 386, 1997

um chamber wouldn't work, but I said it depended on the design and that I could make it work. To prove my case, I went away and grew single-crystal GaN on a sapphire substrate – using MBE - and showed my photoluminescence results to MITI to confirm that GaN could indeed be grown in the way I had proposed. My research proposal was then accepted. Unfortunately, though, the results of the work are recorded only in a report to MITI and nowhere else. I filed a patent, of course, but I really regret not having published the work internationally in English.

OBI What happened after that? Did you make any other successful research proposals related to GaN?

Professor Akasaki: Yes, I did. I proposed growing GaN by MBE as well as hydride vapour phase epitaxy and then using an ion-implantation technique to fabricate a blue light-emitting device. However, another researcher, Dr. Izuo Hayashi of NEC, who had returned to Japan from Bell Labs in 1971, had different ideas for achieving devices to emit light of the same wavelength. His competing proposal was to fabricate a blue laser by using second harmonic generation (SHG) with a GaAs laser.

Fortunately, MITI was favourably disposed towards both proposals and decided to back both approaches simultaneously. So MITI established a sort of consortium to manage the research. The consortium consisted of the late Dr. Kenjiro Sakurai, then the General Manager of Electrotechnical Laboratory, as the Chairman, Professor Shoji Tanaka of the University of Tokyo, myself, and Dr. Hayashi. This form of project was quite unique in those days – the Government was not yet accustomed to funding other organisations to carry out research: it showed the importance of the project.

In the end my group succeeded in fabricating the first nitride-based flip-chip type MIS LED and reported the results at the International Symposium on GaAs and related compounds held in Oiso, Japan in 1981 (see *Inst. of Phys. Conf.* Ser. 63, 479 (1981)). The crystalline quality of GaN was still very poor, though. This led many other researchers to lose heart and stop researching into GaN. However, a number of the more determined scientists, particularly in Japan, decided to continue working in the field. That was how we could succeed in drastically decreasing the density of micro- and macroscopic defects to a level where good *p-n* junctions and device structures could be achieved.

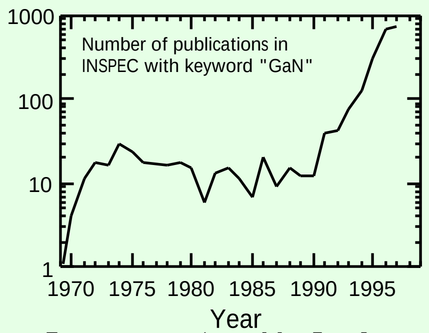
OBI So this period of research certainly seems to have been the source of the current worldwide interest in this field (see figure). But now let's move on to talk about science and education more generally. Do you have any thoughts about how to encourage youngsters to take a greater interest in science and engineering?

Professor Akasaki: I think that young people today have too few occasions to touch and handle the actual working parts of machines, modern electronic gadgets and so on. When I was a young researcher, I used to build my own annealing ovens and furnaces, solder all my electrical contacts manually – I had very little equipment that was automated. Hands-on interactions with that kind of technology is exciting and educational. It continually brings surprises and new discoveries on a very personal level - it stimulates the mind and creates an interest in science and engineering.

These days, though, most equipment for characterisation in universities and industry is highly automated. So students aren't encouraged to think much about its internal workings... It's like using an electronic calculator to give you an answer without your really having to think about how it was derived. My real concern is that "educators" may themselves reach the stage where they do not know enough about the internal workings of devices, machines and so on. We may pay an unexpectedly high price for all the conveniences of the modern age.

OBI: We are approaching the 21st century. In your opinion, what idea or discovery has had the greatest influence in shaping our lives in the 20th century?

Professor Akasaki: I think the 20th century was truly the century of "electronics": telecommunications technology, especially, has advanced at a tremendous rate. In the early days we were dependent on vacuum tube technology but in the 1950's the vacuum tube was replaced by solid state devices.



From a presentation at Mat. Res. Soc Symp. D (Dec. 1997) by I. Akasaki.

Semiconductor technology now governs our daily lives.

OBI: Then what about the 21st century?

Professor Akasaki: That is a difficult question! It may be fashionable to say "biotechnology" and such-like, but I do not believe that electronics will give up its dominant position for a very long time to come.

OBI: Finally, Professor Akasaki, do you have time to pursue any hobbies?

Professor Akasaki: I enjoy "conversation". I think it is important to talk – opportunities for discussing things with people from a wide range of backgrounds and opinions are not so frequent in this country. I always encourage my students to hold discussions, not just about their research but ranging much wider, over topics such as art, music and history.

My other, more serious pastime is listening to classical music using amplifiers that I have built myself from vacuum tubes. I also design and build my own speaker systems–the biggest "woofer box" I have is about 1.5 metres high. My hobby makes moving house very difficult!

Interview by Adarsh Sandhu

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`http://www.jpo-miti.go.jp`. A useful site for reviewing Japanese patent literature

`http://www.aiej.or.jp`. Short English language descriptions of all Japanese universities with links to their home pages.

Publications

Japan 1998 – An International Comparison. An excellent booklet with facts, figures and numbers comparing such topics as GDP, R&D expenditure, propensity to save between Japan and the rest of the world. Published by Keizai Koho Centre. 900 Yen. Contact: `webmaster@kkc.or.jp`

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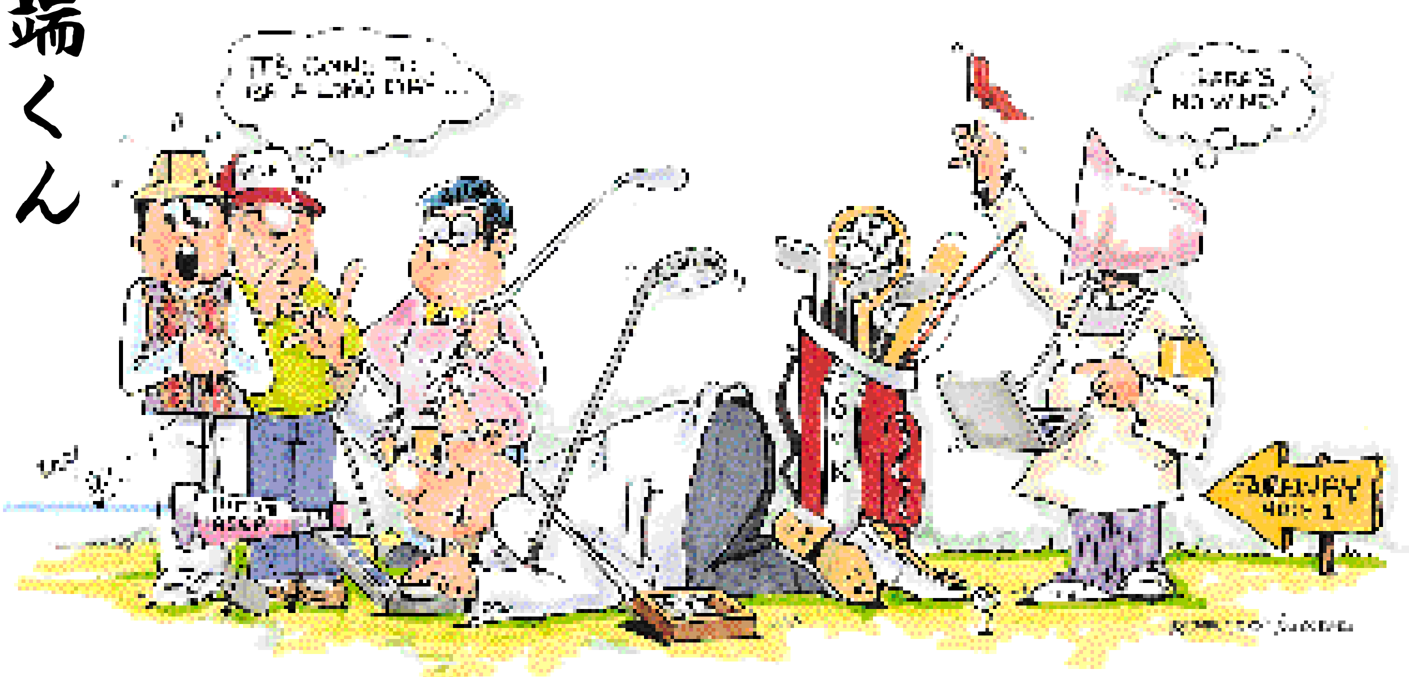

"ONE FINAL CHECK ON THE WIND AND DISTANCE ... AND I THINK WE'RE ABOUT READY TO INITIATE A LAUNCH!"

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Scientific Japanese

As in any language, there are words in specialist fields which do not appear in dictionaries of the standard vocabulary. In this section, an abstract from this month's *Oyo-Buturi* is translated into English and a vocabulary of scientific and technical Japanese terms is presented.

重力波検出用大型レーザー干渉計用周波数安定化レーザーの開発の経緯とそれから発生した種々の研究を紹介する。LD励起YAGレーザーに能動的周波数制御をかけて 1.5×10^{-19} Hz$^{-0.5}$ の安定度を実現したが、これは 47mW 出力のショット雑音限界であった。基準共振器に不可欠のppm損失ミラーの開発は、周波数安定化レーザーによる光学パラメータ計測法の開発と平行して行われ、我が国でも1.5ppm損失や99.996%反射が達成できるようになった。量子限界を向上するための努力は、高出力レーザーの拡大則を再検討させ、VPS レーザーや注入ロック方式が開発された。さらに科学研究とは対極の産業応用レーザーとして、高出力ファイバーレーザーが重力波検出用レーザーの研究から生み出された経過を紹介し、極限レーザーの研究を行った意味を改めて検証する。

The circumstances concerning the development of a frequency-stabilised laser for a large-scale interferometer, which is to be used for the detection of gravity waves, and the wide range of research activities generated by the project are introduced. Stabilisation of 1.5×10^{-19} Hz$^{-0.5}$ was realised by using active frequency control on a YAG laser, which was pumped by a laser diode, thereby reaching the shot-noise limit for an output power of 47 mW. The development of parts per million (ppm) loss mirrors, which are essential for optical resonator standards, has been carried out in parallel with the development of optical parameter measurement techniques with a frequency-stabilised laser, and Japan is now able to fabricate mirrors with 1.5 ppm loss and 99.996% reflectance. The effort to push back the quantum noise limit led to the re-examination of the rules with regards to scaling up high power output lasers, and led to the development of the VPS laser and injection locking system Furthermore, we describe how, at the opposite end to scientific research, the industrial, high-power, fibre-laser was developed from the research work carried out to produce a laser for gravity wave detection, providing further justification for the research work on lasers at the extreme limits.

重力	jyūryoku	gravity
重力波	jyūryokuha	gravity wave
レーザー	rēzā	laser
干渉	kanshō	interference
干渉計	kanshōkei	interferometer
励起	reiki	excite
能動的	nōdōteki	active
周波数	shūhasū	frequency
制御	seigyō	control
雑音	zatsuon	noise
限界	genkai	limit
共振器	kyōshinki	resonator
計測法	keisokuhō	measurement method
量子	ryōshi	quantum

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