KOBAYASHI Kohroh 2010-KK-E-Tokyo-Tech-EEIC-Engrg.

"Single Transverse and Longitudinal Mode Semiconductor Injection Lasers for Long Wavelength Optical Fiber Communications"

1. Biography

(KOBAYASHI Kohroh)

1944-10 Born, 1968-03 Tokyo Institute of Technology Bachelor's degree, 1970-03 Tokyo Institute of Technology, Master's degree, 1977-06 Tokyo Institute of Technology Doctor of Engineering. 1970-04 joined NEC Corporation, engaged in research and development of semiconductor lasers for optical communication, 1991-07 General Manager, NEC Opto-Electronics Research Laboratories, 1999-04 Vice-President Research, NEC Corporation, 2002-04 Professor, Tokyo Institute of Technology, 2008-04 President of Precision and Intelligence Laboratory, Tokyo Institute of Technology, 2010-03 Professor Emeritus, Tokyo Institute of Technology.

He received Okochi Memorial Technology Award in 1987-03(Shared), IEICE Achievement Award in 1989-05(Shared), and IEICE Distinguished Achievement and Contributions Award in 2009-05. He is IEEE Fellow in 1996-01, IEICE Fellow in 2006-09, JSAP Fellow in 2007-08 and IEICE Honorary Member in 2010-05.

2. Summary

KOBAYASHI Kohroh achieved significant work on semiconductor lasers for optical fiber communications. In 1970's, he engaged in fundamental research in NEC's research laboratories including relaxation oscillation suppression by optical injection locking, optical feedback induced anomalous phenomena such as multi-steps in the current vs. light output (I-L) curve, and transverse-mode instability which induced a strong saturation in I-L curve and modal profile deformation. In 1980's, his main R&D topics turned to semiconductor lasers for long-haul wide-band long wavelength optical fiber communications. He developed and commercialized high performance stable fundamental transverse mode and single longitudinal mode semiconductor lasers with InGaAsP/InP materal systems. After moved to Tokyo Institute of Technology in 2002, he challenged most advanced topics such as all-optical signal processing and mode-locking surface emitting lasers.

3. Research Summary

3.1 Achievement of Semiconductor Laser Research in 1970's

Kobayashi Kohroh graduated master course of engineering at Tokyo Institute of Technology in 1970, and joined NEC where he engaged in research and development of semiconductor lasers for optical communications. He enjoyed the first CW oscillation of AlGaAs/GaAs semiconductor laser at room temperature for the first time in Japan[1].

(a) Relaxation Oscillation Suppression:

Strong relaxation oscillation in the light output from semiconductor laser was supposed to become a serious drawback for application to the high speed optical fiber communications. Dr. Teiji Uchida, a leader for the semiconductor laser application research group, claimed to eliminate it. Dr. Roy Lang proposed external optical injection method based on the theoretical work. Kobayashi Kohroh tried to verify the method and succeeded in experiments using AlGaAs/GaAs semiconductor lasers, as shown in Fig. 1[2]. Later it was recognized as a most pioneering experiment of optical injection locking which has been applied to expand the modulation bandwidth.

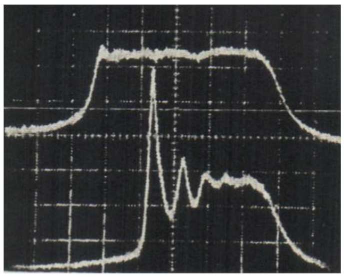

Fig. 1 Relaxation oscillation suppression by injection locking[2]. 1ns/div.

(b)Optical Feedback-induced Instability:

It was demonstrated that a semiconductor laser with optical feedback induced multistable characteristics in the current vs. light output (I-L) curve [3]. It was also shown that the dynamic properties of semiconductor lasers are also significantly affected by external feedback, depending on coherent interference conditions between returned light and the field inside the laser diode. Theoretical work was done by R. Lang. The basic equation was called "Lang-Kobayashi's equation[3] and widely applied to analysis of laser cavity with external feedback light or external injected light. Since these interference effects occur with a quite small amount of the external reflection, it was suggested that to realize fully stable operation of semiconductor laser, a reciprocal optical device such as an optical isolator should be inserted between the laser and the external circuits.

(c) Transverse-Mode Instability:

In AlGaAs/GaAs gain-guiding semiconductor lasers, anomalous lasing properties, such as kinks in the current vs. light output (I-L) curves and rapid damping in the light output relaxation oscillation, appeared reproducibly. It was found experimentally and theoretically that these anomalies were caused by unstable horizontal transverse mode-wave guiding[4]. The guiding is weakened with the excitation due to the uneven carrier consumption by the uneven stimulated emission in the horizontal direction. A key point to remove such anomalies relies on the introduction of definite transverse mode guiding mechanism in the laser structure. A new stripe laser geometry was invented and verified experimentally by H. Yonezu. The conclusion of this work, a solid and fixed waveguiding is necessary for stable and high-performance semiconductor lasers, has linked to the research and development of high-performance long wavelength semiconductor lasers for single mode optical fiber communications described in 3.2 in this article.

3.2 Research and Development of High-Performance Semiconductor Lasers for Single-Mode Optical Fiber Communications

Research and development of optical fiber communications moved from the multi-mode fiber-short wavelength (0.8 μm) systems in 1970's to single-mode fiber-long wavelength (1.2-1.6 μm) systems in 1980's. Strong requirements were brought to us to develop single transverse mode semiconductor laser at the long wavelength, followed by single longitudinal mode (single frequency) lasers. Based on the knowledge obtained in the R&D of AlGaAs/GaAs short wavelength lasers described in 3.1(c), semiconductor lasers with excellent performance have been realized and installed into commercial optical transmission equipments.

(a) InGaAsP Double-Channel-Planar-Buried-Heterostructure Laser Diodes (DC-PBH LDs)

For the definite transverse-mode waveguiding, a buried heterostructure was adopted, where an InGaAsP active region stripe was embedded in an InP cladding. A p-n-p-n current blocking structure was made by liquid-phase epitaxy on both sides of the active-stripe mesa which was defined by a pair of channels (i.e., double channels). The DC-PBH LDs were invented and grown by Ikuo Mito (Fig. 2)[5]. Due to the strong photon and carrier confinements, DC-PBH LDs demonstrated excellent performances such as a differential quantum efficiency of 78 percent, an electrical to optical conversion efficiency of 43 percent, and fundamental-mode light output power of 50 mW at 1.3 μm wavelength region at room temperature. CW oscillation was possible up to 130 ℃. Similar results were obtained later in 1.5 μm band. These devices have contributed significantly to expand applications to the long-haul, wide-band optical fiber communications.

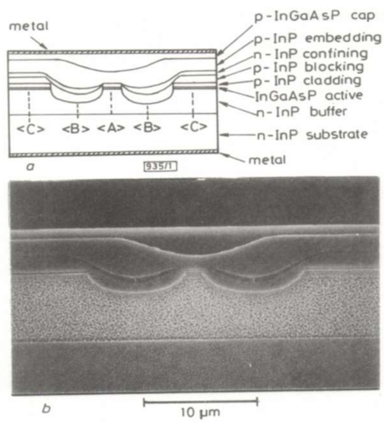

Fig. 2 InGaAsP stable fundamental transverse-mode laser diode[5]

(b) Single-Longitudinal-Mode Distributed-Feedback Semiconductor Laser Diode (DFB-DC-PBH LDs)

Single frequency spectrum was needed for light sources for long-haul wide-band optical iber communication systems at 1.55 μ m wavelength regions under high-speed direct modulation. This condition was crucial to enjoy the low-loss wavelength region of a silica single-mode optical fiber to be free from the wavelength dispersion effect. A corrugation for distributed feedback (DFB) was introduced into a stable single transverse-mode DC-PBH structure, resulting in a high-performance 1.5 μ m DFB-DC-PBH LD, as shown in Fig.3 [6]. Among the lasing characteristics are high-power over 20 mW and high-temperature CW operation over 75 ℃ under single frequency operation.

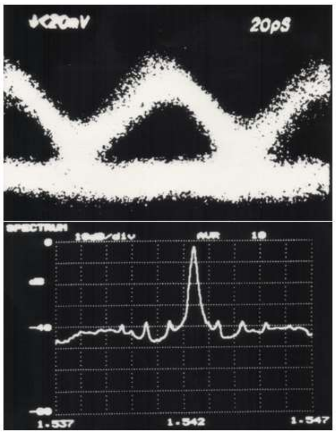

Fig.3 Single frequency operation of 1.5μ m DFB-DC-PBH LD at 10Gb/s[6]

3.3 Advanced Trials in Tokyo Institute of Technology

After moved to Tokyo Institute of Technology in 2002 as a professor, he decided to make research on most advanced trials including all-optical signal processing and mode-locking of a surface emitting laser.

(a)All-Optical Label Bit Recognition

All-optical signal processing has been expected to offer advantages in speed and power consumption against conventional electronic signal processing. So far, two-bit label was recognized all-optically using SOA-MZI (Semiconductor Optical Amplifier-Mach-Zehnder Interferometer) all optical switch and a wavelength converter. Loopback method was introduced to reduce the number of all-optical switches. A basic function was confirmed experimentally. However, label bit number expansion and power consumption reduction were remained to be solved.

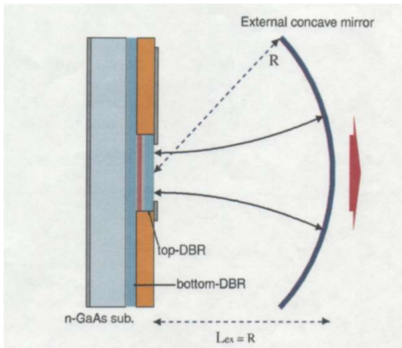

Fig.4 External-cavity VCSEL for Mode-locking[8]

(b)Sub-Harmonic Active Mode-Locking of an External Cavity VCSEL

A composite resonator VCSEL (Vertical Cavity Surface Emitting Laser) was designed combining a VCSEL chip and a concave external mirror for mode-locking to produce high-speed optical signals over the direct modulation bandwidth. Using a concave mirror with the curvature radius of 14.12mm, 10.56GHz repetition signal was obtained with RF electrical signal injection of 3.52 and 5.28GHz, corresponding to a third and a half of the cavity resonance frequency. This was a result of sub-harmonic mode-locking of the external cavity VCSEL[8]. Another experiment with an external concave mirror of 4.71mm radius showed 31GH repetition signal by a half subharmonic mode-locking. In this configuration, a wide concave mirror position tolerance of over 120 μm was observed by a unique double-path resonance.

4. REFERENCES

[1] I. Sakuma, H. Yonezu, K. Nishida, K. Kobayashi, F. Saito and Y. Nannichi, "Continuous Operation of Junction Lasers at Room Temperature," Japan. J. Appl. Phys., Vol. 10, pp. 282-283, 1971.

[2] R. Lang and K. Kobayashi, "Suppression of Relaxation Oscillation in the Light Output of Semiconductor Lasers," IEEE J. Quantum Electron., Vol. QE-12, pp. 194-199, Mar. 1976.

[3] R. Lang and K. Kobayashi, "External Optical Feedback Effects on Semiconductor Injection Laser Properties," J. Quantum Electron., Vol. QE-16, No. 3, pp. 347-355, Mar. 1980.

[4] K. Kobayashi, R. Lang, H. Yonezu, Y. Matsumoto, T. Shinohara, I. Sakuma, T. Suzuki and I. Hayashi, "Unstable Horizontal Transverse Modes and Their Stabilization with a New Stripe Structure," IEEE J. Quantum Electron., Vol. QE-13, No. 8, pp. 659-661, Aug. 1977.

[5] I. Mito, M. Kitamura, Ke. Kobayashi, S. Murata, M. Seki, Y. Odagiri, M. Yamaguchi, and Ko. Kobayashi, "InGaAsP Double-Channel-Planar-Buried-Heterostructure Laser Diode (DC-PBH LD) With Effective Current Confinement," J. Lightwave Tech., Vol. LT-1, No. 1, pp. 195-202, Mar. 1983.

[6] M. Kitamura, M. Yamaguchi, S. Murata, I. Mito and K. Kobayashi, "High-Performance Single-Longitudinal-Mode Operation of InGaAsP/InP DFB-DC-PBH LD's," J. Light-wave Tech., Vol. LT-2, No. 4, pp. 363-369, Aug. 1984.

[7] J. Kurumida, H. Uenohara and K. Kobayashi, "A New Loopback Method of All-Optical Label Processing for Label Bot Scalability," Photonics Tech. Letts., Vol. 20, No. 9, pp. 745-747, May 2008.

[8] T. Kato, A. Matsutani, T. Sakaguchi, and K. Kobayashi, "Sub-harmonic mode-locking of VCSEL with a concave external mirror," IEICE Electronics Express, Vol. 5, No. 4, pp.152-156, Feb. 25, 2008.

2021-6-26 KOBAYASHI Kohroh presented