D1. Solid State Microwave Sources

Device performance in microwave applications has been improved rapidly in terms of output power, gain, power-added efficiency, and integration. In a base station for mobile communications, an output power of 140W with a power added efficiency of 42% was obtained by using hetero-junction FET [Takenaka et al., 1998]. Several technologies demonstrated the power amplifier performance for handsets. A two-stage HBT amplifier exhibited a power-added-efficiency of 63.2% and an adjacent channel leakage power at a 50-kHz offset frequency of -52dBc in 1.5GHz PDC standard [Iwai et al., 1998]. Using HJFET technology, a power-added efficiency of 64.0% with an adjacent channel leakage power of -48.7dBc and an output power of 30.1dBm was obtained under single 3.5V operation [Bito et al., 1998]. Si MOSFET also provided a high power-added-efficiency of 62% with an output power of 27.1dBm [Matsuno et al., 1998]. Monolithic integrating front-end circuits, including a power amplifier, a low noise amplifier, a switch, and a negative voltage generator were developed in SAGFET [Choumei, et al., 1998].

To meet the requirements of millimeter-wave applications such as satellite communications, local bi-directional communications, and automotive radars, several MMICs have been developed mainly using hetero-structure devices. In Ka-band, a switched-line phase shifter MMIC incorporating unresonated switches demonstrated a phase deviation of 3.3deg rms at 34.5 GHz. The circuit was fabricated with 0.15-mm T-shaped-gate HJFETs [Maruhashi et al., 1998a]. Two-stage low-noise amplifier MMIC achieved a noise figure of 1.0 dB with an associated gain of 18.0dB at 32GHz, using a AlGaAs/InGaAs/GaAs pseudomorphic HEMT with a gate length of 0.15mm [Fujimoto et al., 1997]. A 38GHz-band monolithic voltage controlled oscillator exhibited a phase noise of 85dBc/Hz at a 100kHz offset and an output power of 8.4dBm. The circuit was designed with an AlGaAs/InGaAs HBT with p+/p regrown base contacts[Tanji et al., 1998]. A V-band MMIC chip set consisting of a receiver MMIC with a noise figure of 6.5dB and a transmitter MMIC with an output power of 17.7dBm has been developed with HJFETs[Mizoe et al., 1997]. A W-band T/R MMIC chip set for automotive radar systems has been fabricated using pseudomorphic HEMT with a gate length of 0.15mm[Kamozaki et al., 1997].

Cost reduction is the key to the millimeter-wave market. Several methods have been proposed for low-price high-frequency systems. Flip-chip technology was employed to realize low-cost MMIC assembly. For 76GHz automotive radar systems, a flip-chip bonded amplifier has been developed [Murahashi et al.,1998b][Hirose et al., 1998]. The chip set has also been fabricated using flip-chip packages and HEMTs with a gate length of 0.15mm[Ohashi et al., 1998]. A master-slice architecture is another approach for cost reduction, which is popular in digital circuits. A V-band amplifier has been demonstrated with a three-dimensional MMIC master-slice structure and heterojunction MESFETs, obtaining a noise figure of 5.3dB [Nishikawa et al., 1998].

As an emerging device technology, resonant tunneling diodes and HEMTs have been integrated in a monolithic injection-locked oscillator. Due to the strong nonlinear characteristics of resonant tunneling diodes, the circuit can be locked for 128 higher-order
subharmonics [Kamogawa et al., 1998]. The wafer-scale MMIC approach has been proposed as an advanced technology [Toyoda et al., 1996].

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D2. Gas and Solid -State Lasers

By using the mature LD (Laser Diode) technology with high electrical efficiency, performances of all solid-state lasers have been improved dramatically in recent years. By combination of nonlinear crystals, it becomes easy for the all solid-state laser to generate a variety of wavelengths from UV to IR. A part of gas lasers have been replaced with solid-state lasers and then lamp-pumped solid-state lasers have been also replaced with LD pumped solid-state lasers.

ArF excimer lasers (193nm) have been studied intensively for the 1Gbit DRAM lithography and medical applications [Sekita et al., 1995]. Spectral narrowing up to 1-pm [Tada, et al., 1996] and long lifetime operation up to 100 million shots [Saito et al., 1996] were achieved.

High-order harmonics VUV lights were generated from rare gas (He, Ne) as nonlinear medium with Ti:sapphire laser [Miyazaki, et al., 1996][Kobayashi et al., 1996] and KrF excimer laser [Nagata et al., 1996]. Soft X-ray laser was also reported [Midorikawa et al., 1996].

High green power of 20W was generated with 14.2% optical-to-optical conversion efficiency from the intracavity-frequency-doubled Nd:YAG laser [Konno et al., 1997], and the intracavity compact SHG green laser was reported [Kitaoka et al., 1996]. UV light (213nm) was generated as a fifth harmonics of Nd:YAG with average power of 0.5W[Matsuda, et al., 1997], and VUV (193nm) light was obtained as a forth harmonics of Ti:sapphire laser [Kasamatsu et al., 1997].

Performances of tunable solid-state lasers have been improved. Broadband [Izawa et al., 1996] and electronically tuned Ti:sapphire laser [Wada et al., 1996] were reported. Tunable lasers are also useful to generate the fs short pulse. Extremely short pulse of 89 fs was generated from Cr:LiSAF laser [Ashida et al., 1997]. A single-mode Cr:LiSAF laser as an injection-seeder of the Ti:sapphire laser was developed [Maeda et al., 1996].

In 1997, NEDO(New Energy and Industrial Technology Development Organization) started the large-scale national project to realize the high power all solid-state lasers whose output powers will be 1kW with high beam quality or 10kW at the final goal in FY2001. TEM00 mode operation(M2<1.1) with high power of 208W was achieved[Hirano et al., 1998] under this project.

Novel lasers with new laser crystals and pumping configurations have been investigated to
realize the higher power and new wavelength. Laser diode pumped zigzag slab Nd:YAG MOPA (Master Oscillator Power Amplifier) system generated 1.26J/pulse at the repetition rate of 200Hz [Tei et al., 1996]. High energy extraction efficiency of 73% was achieved with the eight-pass zig-zag slab laser amplifier [Kiriyama et al., 1998]. Yb lasers with high quantum efficiency due to quasi-three levels were studied [Taira et al., 1997][Kasamatsu et al., 1998]. All-solid-state Ce:LiSAF master oscillator power amplifier (MOPA) system generated UV short pulse[Sarukura et al., 1996]. Simultaneous cascade oscillation in the 3mm and 2mm bands with Ho3+ doped fiber laser was demonstrated [Sumiyoshi et al., 1997].

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### D3. Semiconductor Lasers and Detectors

Long-wavelength InP-based distributed feedback (DFB) lasers integrated with a multiquantum-well (MQW) electro-absorption (EA) modulator have been intensively studied for the application to 2.5-Gbit/s long-span (700-800km) optical-fiber transmission systems [Ishizaka et
The wavelength control of the DFB lasers for DWDM systems has been researched as the different wavelength DFB lasers (1.53-1.59 mm) on a single wafer [Kudo et al., 1997]. The new techniques to precisely control the wavelength have been developed as follows: 1) EB lithography fabricated grating [Muroya et al., 1998], 2) the wavelength trimming technology [Sudoh et al., 1997] and 3) the low temperature lasing wavelength discriminator (0.2 A/deg) [Tsuzuki et al., 1997]. Also, an InP-based polarization-insensitive arrayed-waveguide-grating filter was demonstrated [Koutoku et al., 1998]. EA modulator has been applied to 40-Gbit/s modulation [Takeuchi et al., 1997; Yamada et al., 1997]. And, 1.54 THz optical pulses were generated by mode-locked distributed-bragg-reflector lasers [Arahira et al., 1996].

Wide-temperature-range (WTR) operation of long-wavelength Fabry-Perot and DFB lasers for use in access networks has been extensively researched by using the following approaches: 1) an InAlGaAs material system (To=122 K [Ohnoki et al., 1998], To=143 K [Anan et al., 1998]), 2) reverse-trapezoid ridge-waveguide structure (lasing up to 165 C [Aoki et al., 1997]), 3) InGaAs ternary substrates (lasing up to 210 C [Otsubo et al., 1998]), and 4) novel GaInNAs (To=127 K [Kondow et al., 1997]). The dominant mechanism that causes low To in InGaAsP/InP lasers was investigated from the viewpoint of the spontaneous emission efficiency [Higashi et al., 1997]. Moreover, the following milestones have been attained: 1) narrow-beam divergence lasers integrated with a spot-size converter for low-cost optical modules [Itaya et al., 1997; Kobayashi et al., 1997; Kasukawa et al., 1997; Aoki et al., 1997], 2) fabrication of a low-threshold monolithic laser array with a 1-mA range for optical interconnection (n-type modulation-doped MQW lasers [Nakahara et al., 1997], 3) Al-oxide confined inner stripe lasers [Iwai et al., 1998], 4) complex-coupled WTR-DFB lasers [Kito et al., 1996], and 5) WTR-DFB lasers for CATV applications [Watanabe et al., 1997].

Short-wavelength lasers are very important as light sources for high-density information-processing systems. The first RT-pulsed operation [Nakamura et al., 1996A] and first RT-CW operation [Nakamura et al., 1996B] of a wide-gap InGaN-based laser was at a wavelength of 400 nm and reliability of more than 1,000 hours was achieved [Nakamura et al., 1998]. The shortest wavelength semiconductor laser (376 nm) was also demonstrated [Akasaki et al., 1996]. Moreover, the lifetime of wide-band-gap II-VI lasers has been improved to 400 hours [Kato et al., 1998].

High-power semiconductor laser technology has been demonstrated by applying a window-mirror structure to suppress the catastrophic optical damage or applying an Al-free material system. As a result, 650-nm laser diodes [Shima et al., 1997], 980-nm laser diodes [Sagawa et al., 1997; Fukagai et al., 1997; Yamamura et al., 1998], and 1.06-mm laser diodes [Asano et al., 1997] have been developed. Also, W-range optical power was achieved by using a decoupled confinement heterostructure in GaAs/AlGaAs laser diodes [Fujimoto et al., 1998].

Research on vertical-cavity-surface-emitting lasers (VCSELs) has produced stable polarization control by using (311)A substrates [Takahashi et al., 1997], 10-Gbit/s transmission [Hatori et al., 1998], GaAs-substrate-based GaInNAs [Kondow et al., 1997], and lasing emission by photopumping InGaN [Someya et al., 1998]. A low-threshold current in quantum-dot (Q-DOT) lasers was achieved by using a new formation of columnar-shaped dots [Mukai et al., 1998]. Semiconductor optical amplifier (SOA) gate modules with very low operating current and uniformity of 9.7±0.5 mA to provide fiber-to-fiber gain of 0 dB have also developed [Kitamura et al., 1997].

High-speed 152-GHz uni-traveling-carrier photodiodes have been realized by using only electrons as active carrier [Ishibashi, 1998]. A low-dark current (0.27 nA) waveguide photodiodes with Fe-doped InP blocking layer have been reported [Aoyagi et al., 1997]. Highly reliable superlattice avalanche photodiodes with a planer structure have been developed for 10
Gbit/s application [Watanabe et al., 1997]. A 0.95 W/A edge-illuminated refracting-facet photodiode has been developed for low-cost optical module applications [Fukano et al., 1997]. Highly-reliable waveguide photodiodes with 10,000-hours operation at 85C / 85% RH have been developed for low-cost plastic packages [Nakamura, 1998].

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D4. Laser Applications

Remarkable progress has been achieved in high capacity WDM transmission experiments by using wideband EDFAs. Tera-bit/s WDM transmissions have been achieved (55 wavelength x 20Gb/s over 150km [Onaka et al., 1996], 132 wavelength x 20Gb/s over 120km [Yano et al., 1996], and 50 wavelength x 20Gb/s over 600km [Aisawa et al., 1998]). In the TDM area high capacity transmission has been reported by using an ultrashort pulse train (640Gb/s over 60km [Nakazawa et al., 1998]). Soliton transmission technology has also advanced with the use of EDFAs. High speed and long distance soliton transmission experiments have been demonstrated (5 wavelength x 20 Gb/s over 10,000km [Nakazawa et al., 1997] and [Edagawa et al., 1997]).

Optical analog transmission technology for CATV applications has shown much progress. In order to improve the yield of DFB laser a novel partially corrugated design has been developed [Okuda et al., 1996] and for upstream communication low cost coaxial DFB laser module was developed [Nakabayashi et al., 1997].

Photonic switching technology has been greatly progressed to realize optical communication networks. 10 Gb/s photonic cell switching was demonstrated by using 4 x 4 hybrid optical matrix switch module on silica-based planar waveguide platform [Kato et al., 1998]. Semiconductor arrayed waveguide gratings were also reported and polarization-independent InP arrayed waveguide filter was realized [Kohtoku et al., 1997]. VCSELs for optical interconnect have also advanced and 10Gbps transmission experiment using InGaAs-GaAs quantum well VCSEL was reported [Hattori et al., 1998].

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D5. Cryoelectronics

An ultra-high throughput of digital data switching is one of various advantageous characteristics offered by the superconducting electronics. As an initial step toward this end, a three-node ring-pipeline superconducting switching network system was proposed [Tahara 1995]. This system was expected to provide a throughput of greater than 10 Gbps based on the ATM communication technology. The circuit employed the niobium Josephson technology and the core system operated at the liquid herium temperature. A prototype small system was constructed with three PC’s at the ring-pipeline nodes. Moving image data transfer experiments were demonstrated at a rate of 600 Mbps with a data width of 2 bytes [Yorozu 1998].

Application of high-Tc superconductors to the digital electronics depends on the Josephson
junction quality which remains to be improved. The critical current uniformity in the high-Tc Josephson junctions was improved by employing a new substrate material of lanthanum-strontium-aluminium tantalate combined with the in situ etching process. With this method, a value of as low as 16% was attained for the one-sigma critical current spread for 48 junctions [Sato 1998].

Another important area of the cryoelectronics is the microwave application of high-Tc superconductors. A Superconducting filter subsystem was developed aiming for the use in mobile telecommunication systems [Ueno 1998]. The subsystem was equipped with an 11-pole microstripline band-pass filter made of an yttrium-barium cuprate high-Tc superconducting epitaxial thin film together with a low-noise preamplifier and a Starling cryocooler. It operated at 70 K with an insertion loss of less than 0.1 dB and a noise figure of 0.5 dB.

A prototype power transmission microwave bandpass filter was fabricated from a high-Tc superconductor thin film with an aim for the use in the mobile power transmission front end of the base stations [Setsune 1998]. The filter provided values of less than 0.2 dB for the insertion loss below an input power of 30 dBm at a center frequency of 5.1 GHz [Enokihara 1996]. The maximum input power was 41.2 dBm (approximately 15 W).

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