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Opto-Electronics Towards Tera-Bits Realm – Impediment and Strategy –

Advances in information and communication technology (IT) have transformed our daily lives, improving social and economic prosperity. Exciting drama is taking place in the past decade and we are forced to go into “e” prefixed society like e-commerce, e-business, e-education, e-shopping mall, etc. The key players there are Personal Computer (PC) presently, and Networking, which requires large-capacity and high-speed data communication beyond at Giga-bits/second ($10E9$) and approaching Tera-bits ($10E12$).

We believed that the broad-band services would be popular definitely in the future, however, did not sure when and how, and looked for new services bridging the present narrow-band network for telephone/FAX to the broadband network where picture/video might be common. Now, it comes not from picture/video communication services but from data communication services triggered by INTERNET. Even 5 years ago, no one thought that it would happen. The biggest impediment related to customers using the ultra-high-speed networking which has been one of the technical targets for researchers in academia has been cleared, fortunately.

Here, I like to review technologies for the “e” prefixed society from the point of Opto-electronics engineers and to show that the innovation is running with mixture of new and legacy, basic and application or quantum and classical technologies rather than on the way of the simple linear model.

Small/venture companies are starting and playing the role of strong and agile engines luring smart researchers and engineers out from big corporate laboratories and universities around the world, in particular in the North America.

Innovation in Telecommunication Technology

The communication technology consists of transmission, switching, terminals and administration/management, and drastic innovation has happened in the transmission technology field in the past quarter of the century. A few Giga-bits/sec transmission can be available without distant-limitation, practically. The enabling technologies are the innovation of quartz glass fiber, semiconductor laser, optical modulator and photo-detector. In the optical fiber field, degradation of optical pulse-shape (approaching the width of pico-sec range) travelling through the low-loss glass fiber can be mitigated by chromatic-dispersion management and non-linearity control (for example, Soliton) and development of fiber-amplifier (Er Doped Fiber Amplifier: EDFA) easily compensate loss penalty due to adding new function as well as the energy loss of fibers.

The idea of the fiber amplifier itself was not new and it became practical by advances of pumping laser diodes with strained layer quantum-well structure in the beginning of '90s. Note that appearance of optical amplifier (fiber amplifier and also semiconductor optical amplifier) can provide wider freedom in design since the power penalty of introducing novel functions in the optical circuits can be easily compensated.

The laser diodes and photo-detectors are made of compound-semiconductor materials, In-GaAsP, owing to fruits of science, the quantum-well structure, the band-gap control with the enabling process-technologies, Hetero-epitaxial crystal growth (LPE, MBE, MOCVD) and device physics on the basis of waveguide structures. German contribution is appreciated in the challenge.

The R & D for the point-to-point transmission had been comfortable since the technical guideline was simple, that is, just the improvement of performance, not necessarily new functions. Recently, the new requirement for multipoints-to-multipoints networking are different and forcing us to change the R & D strategies in which diversification and multiplicity of technologies shall be considered. Some of them may be on the shelf already rather than the front-edge technologies like semiconductor nano-technologies.

The hottest topics now in the transmission technology area has been dense-wavelength-division-multiplex (DWDM) where, instead of using single channel (one wavelength carrier), multi-channels (many wavelengths carriers) carry signals in order to increase the total accumulated bit-rate multiplied by the number of the wavelengths travelling through single fiber. The idea was not new and common in electronic transmission technology, however, the single EDFA, the enabling technology, can amplify the all channels in bulk since the gain-bandwidth is able to cover the all channels. It cannot be performed in the conventional electronic system where many repeaters taking care of each channels shall be used.

80 wavelengths times 40 Gbits/sec equivalent to 3.2 Tbits/sec transmission through one fiber was demonstrated in laboratories and 1 Tbits/sec system using combination of EDFA and Raman fiber amplifiers is waiting for crossing Atlantic-Ocean (Optical Fiber Communication Conf., March 2000). The other enabling technology is the wavelength control and management in optical devices including laser diodes and multiplexing and de-multiplexing devices, that is an optical filter.

Technology Changes Old Idea Most Innovative

Standardized separation of DWDM grid is 25 Ghz in 1550 nm wavelength region which means the optical filter is really a key device. Besides innovative waveguide device like planar-lightwave-circuit (PLC), arrayed-waveguide-grating (AWG) for example, classical and advanced multi-layered-filter is widely used presently in commercially available equipment. As far as switching function in optical communication technology, the optoelectronics has done lot of try to realize the function in vain. Up to now, the digital switching like optical packet-switching was believed only one option for the application and the

big effort has been put on the implementation without quick optical-memory equivalent to C-MOS and delay-line other than using fiber propagation delay. Researchers have to continue to work to overcome the impediment inherent to electro-optics for the future. However, thanks to INTERNET, a router, a new switching gear, for connecting LAN (local-area-network) and MAN (metropolitan-area-network), turns important, in which the high-bit-rate flow switch is significant rather than the exchange of individual message for each customer, that is, the quick digital processing is not necessary.

The breakthrough for the device comes from micro-electro-mechanical technology, MEMS (micro-electro-mechanical-system) consist of classical mirrors with actuator and collimator for I/O fibers, and free space for light beams. In OFC2000, Lucent Tech. disclosed MEMS 112*112 cross-connect (XC) with accumulated switching capacity of 35.8 Tbps and Xros, a new venture company demonstrated 1152*1152 multi-ports MEMS XC which could handle 10 Gbits/sec for each port (up to 80 Gbits/sec in the near future) and would be shipped this summer. The old idea became fresh by Si processing technology and it may be complementary against the impediment in “innovative” opto-electronics. Note that MEMS took attention in the last OFC '99.

Anyway, the legacy idea opened up new horizons for us towards the All Optical Network. Analog Is Still Fan “Being Digital” is the bottom-line concept in “e” prefixed society, however, it doesn't mean only logic-operation will be there. “Digital” will make sense with appropriate hardware which can run the software. If we go into Network Paradigm beyond Desktop Paradigm, more sophisticated technologies to realize versatile terminals shall be necessary. The terminals are only interface to the real world, to people, to society and to nature. In the new paradigm, various kind of intelligent terminals connected to INTERNET through wired or wireless access are emerging.

Note that the Access becomes more and more important as well as the Core Network mentioned above. Appliance, high-technology consumer equipment, might replace present PCs as wearable terminals, for example. Micro-processor (now operating at 800 MHz!) will be one of devices in the terminals and a large portion of the cost will be shared by other devices and also packaging. The significant innovation will be backed by material, quantum and classical physics and device physics and opto-electronics has lot of advantage in the arena as shown in MEMS XC, as example.

Bridge to Broadband Network/Service

We are recognizing that without picture/video communication service our network shall be upgraded into bit-greedy one due to the data communication. Why we could not foresee or overlook the greediness for bits? In voice communication, the communication is “person-to-person” in real-time, and the property of the traffic is determined by human character and behavior. In case of busy of line, we give up to call and no message is entered and remains in the network. Thanks to our impatience, the network can reject overloaded message beyond handling capability of the network. However, the computer-to-computer

communication is absolutely different. He doesn't care about the real-time and has endurance to try and try again to send the message once put into the terminal, then the message is accumulated in the network or in storage for waiting. To avoid the break-down in service, throwing away some of them ("the best-effort") or implementation of advanced network handling more than Gbits in capacity is necessary. "Connection all the time" is also tough condition for the access and core network, however, it can be mitigated in some degree by the packet communication technology in which a line is shared by many customers.

Internet Protocol (IP) defining INTERNET is a kind of it and also utilizing connectionless communication scheme, however, the real situation is tough to the present network. In Japan, mobile-phone compatible with INTERNET becomes boom and congestion in the i-mode center is a big issue for NTT DoCoMo (the number of users is 6.5 m in almost one year!). Congestion happening in the server will be much easier in finding solution. Multiple effects will appear like those in human body in the Networking Paradigm. Any case, it will be good news for researchers as challenge, even though bad news for customers.

Agile Action and /or Continuity and Steady

The last OFC 2000, a major international conference and exhibition like European Conference on Optical Communication (ECOC) is reported showing a new trend in R & D process. The idea presented in the last meeting was demonstrated as products in the booth at the exhibition on the down floor and some of them were presented in the academic conference room and also demonstrated in the booth. The model of R&D in opto-electronics technologies related to the IT field becomes like the model of Si valley, where putting a new idea into the community, we will find business a week later. As to the information and communication technology field, convergence into cluster or integration of various functions backed by new technologies seems necessary for incubating the complicated innovation, in which there are no clear distinction like basic research or application research. INTERNET will be helpful for that, however, human network generated in research society seems more reliable for the agile evolution so far.

The market drive R&D is healthy, if there are many participants from deferent areas. Cross stream of industry and university, and the balance between Agile and Steady become more important now.