Section 4 Current development status of optical transceiver in optical fiber communication in Taiwan

Due to the booming of internet and the larger and larger demand on communication content as well as bandwidth from optical fiber communication users, optical fiber communication and wireless communication are for sure to be two mainstreams of future communication world:

Optical fiber communication: Communication application related to high bandwidth and complex content. For example, VOIP (Voice over IP) and MOD (Movie on Demand)

Wireless communication: For convenient and personalized communication need. For example, the Wireless LAN application

After IT and IC industry, optical fiber communication industry in Taiwan has now gradually formed its cluster as in figure 1-1. In this industry, some companies target at the key active optoelectronic components for optical fiber communication, that is, optical transceiver. That is, they perform product R&D, process design, manufacturing and production and marketing and sales for optical transceiver.

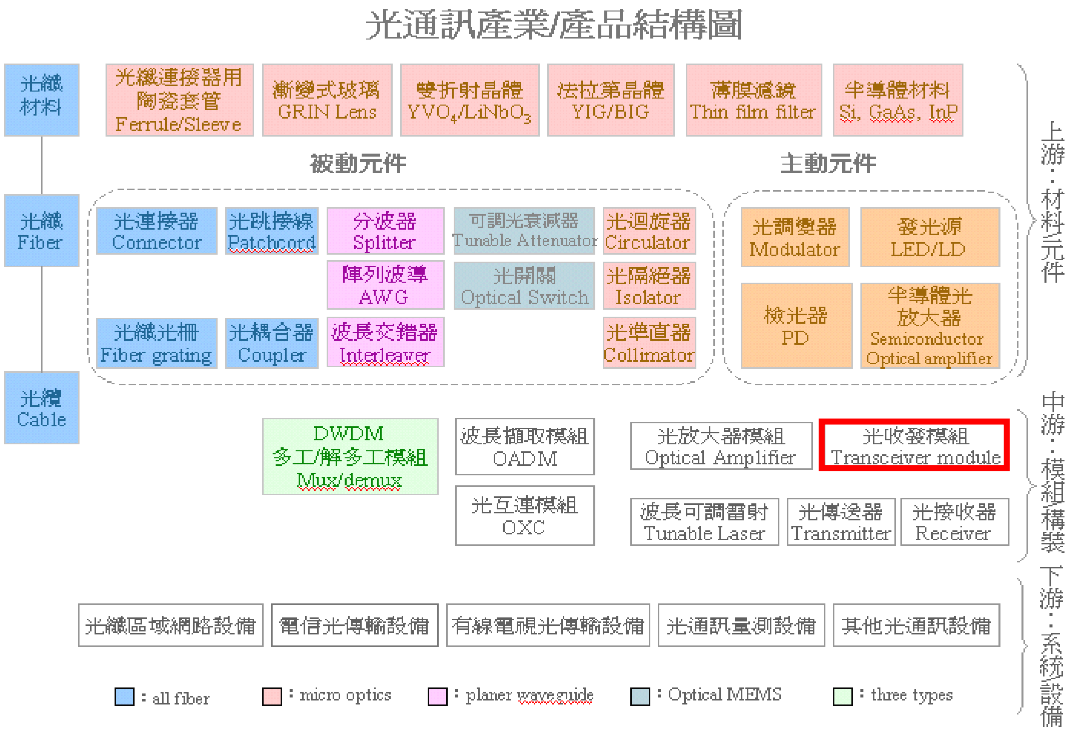


Figure 1-1

Optical fiber communication encountered its great jump in 1999-2000, but unfortunately, the entire internet opportunity booming does not catch up with it; this leads to an over-investment in optical fiber communication industry and a subsequent several years dark period. After nearly four years of decay and inventory digestion and some tiny hope was seen until 2005. The most important active component in optical fiber communication network is optical transceiver; from WAN (Wide Area Network), MAN (Metropolitan Area Network) to LAN (Local Access Network), optical transceiver plays a key role as accurate transmitting and receiving of optical data. Optical transceiver companies in Taiwan emphasize on the vertical integration of up, medium and low streams; although not many companies involve in it, the industry structure is becoming complete. As optical transceiver gradually moves toward miniaturization, the transceiver interface speed gets enhanced relatively and the technology entrance obstacle becomes higher.

Optical transceiver is composed mainly of optical devices (laser, photo diode), IC (for the control of optical devices) and mechanism component (which forms mechanism such as optical sub-module). The entire technology covers optoelectronic, electronic and physic fields and the optoelectronic signal conversion quality decides the data transmitting quality of entire optical fiber communication. Optical transceiver contains first an Optical Transmitter Module which aims at Electrical/Optical (EO) signal conversion, that is, it converts data of electrical signal into corresponding optical signal and optical fiber is used as a transmission medium for transmitting the data; another module is Optical Receiver Module which aims at Optical/Electrical (OE) signal conversion, that is, it converts the optical signal received from optical fiber into electrical signal. The block diagram of Optical/electrical signal conversion module is as in figure 1-2.

According to a survey of Industrial Economics & Knowledge Center of ITRI, the individual component cost ratio for optical device, optical transceiver and IC in optical transceiver is about 6: 3: 1; therefore, IC also plays an important link in such cost structure and this link is now the weakest one in Taiwan’s optical transceiver module industry. Although Taiwan has very complete supply chain for optical transceiver industry, since most of their customers are oversea customers, which leads to Taiwan supplier’s weak independent power related to sales and component purchase; in the transceiver control IC part, it is far weaker part in Taiwan and only very few suppliers can play roles in the industry supply chain. From the earlier group III-V special process to the realization of most IC with CMOS process, we believe that Taiwan should be able to play certain role in this field due to its proud achievement in CMOS process. Finally, this will make the industry value chain of optical transceiver more complete.

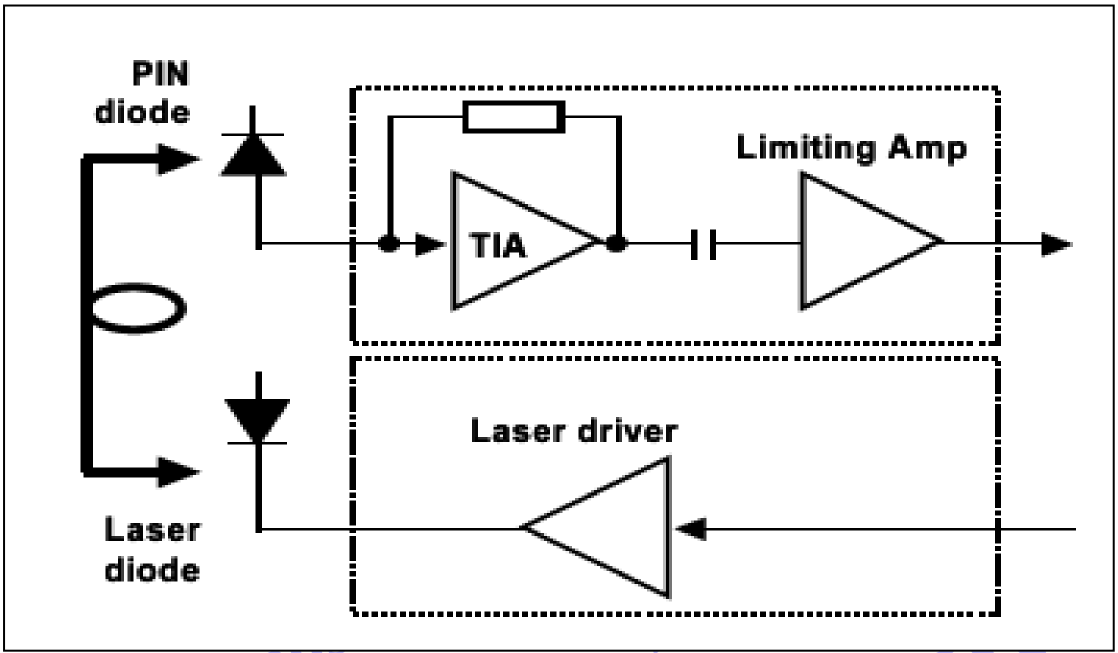


Figure 1-2

Optical transceiver is one of the most important keys for deciding the network data transmission quality in optical fiber communication and it takes the front line responsibility to restore the data. Optical transceiver is composed of OSA (optical subassembly) and optical device control IC; OSA can be divided into TOSA (Transmitter OSA), which includes only laser diode; and ROSA (Receiver OSA), which further contains photo diode and transimpedance amplifier at the receiving end.

In this study, the evolution of current high speed optical transceiver and OSA will be briefly introduced.

The size of optical transceiver get smaller from the earliest 300 pin transponder which has widespread use in telecomm to XENPAK which can be seen in telecomm and datacomm, and finally to very small XFP (as in figure 1-3). The major meaning of different transceiver module is size shrinking, for example, from 3.0×2.2×0.53 (in) of transponder to 2.7×1.4×0.9 (in) of XENPAK and gradually to 2.3×0.7×0.33 (in) of XFP. Furthermore, the electrical I/O of 300 pin transponder uses 16 bit XSBI interface; in addition to optical transmitting and receiving subassembly, there is still CDR (clock and data recovery) circuit for acquiring data and clock; Ser/Des transceiver for series/parallel data conversion which parallelize 10 Gbps high speed data to 16 parallel data with each parallel channel speed of 622 Mbps; however, XENPAK uses 4bit XAUI interface which parallelize 10 Gbps data into four 4 parallel channels, at this moment, the data speed in each channel is raised to 3.125 Gbps; for XFP, the output is direct serial 10 Gbps signal and only clock and data recovery circuit is left. Optical transceiver moves from the earliest 300 pin transponder pig tail module to pluggable small module and the application field also get expanded from telecomm to data transmission application such as: storage, server; it not only provides a small size and high speed module but is extended from WAN to high speed and short distance transmission of LAN nature.

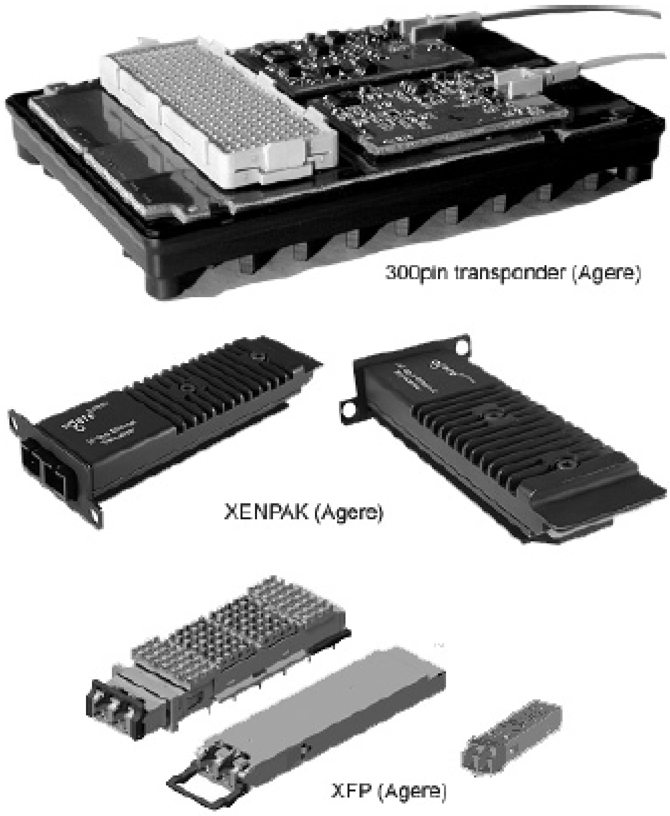


Figure 1-3

Another trend is the emergence of BI-DI, Bi-Directional, transceiver to meet the need of FTTH market in Japan, bi-directional data communication is possible on the same optical fiber (as in figure 1-4). The basic principle behind it is to use two wavelengths and optical refraction so that data upload or download is possible in the same optical fiber.

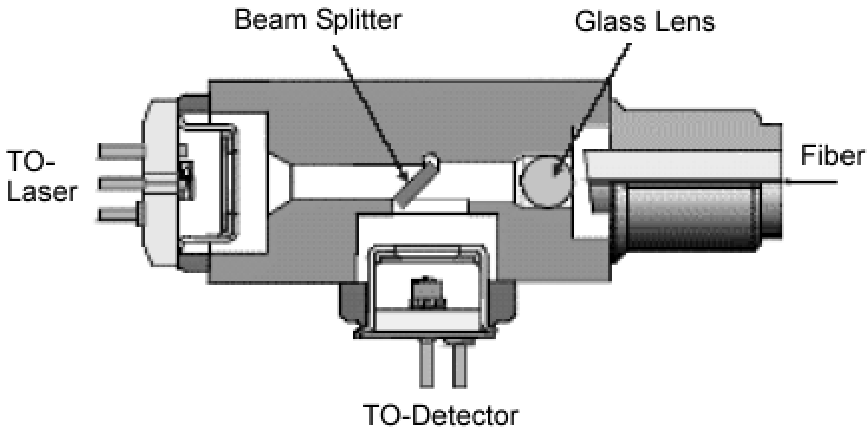
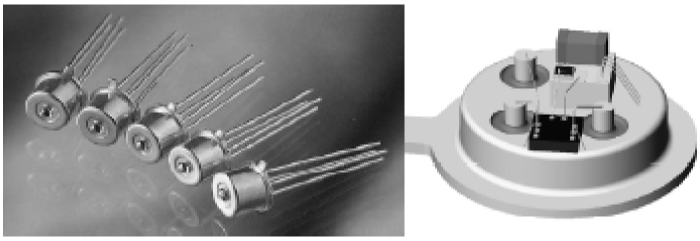
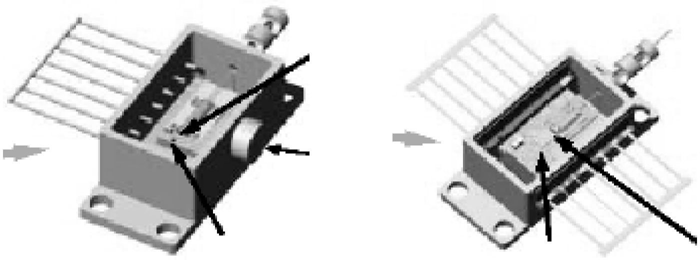


Figure 1-4

The packaging of traditional OSA is usually in the form of TO (Top Open) (as figure 1-5 a). This technology is mature in Taiwan and most packaging companies in Taiwan are competent in mass production of TO OSA. The major disadvantage of TO is the lead count and limited IC space, therefore, not much design can be added for system stability or not many active and passive devices can be added. When transmission speed reaches 10 Gbps, the high frequency effect of TO makes it difficult to adapts to such high transmission speed, butterfly packaging then replaces it (as in figure 1-5 b); in this package, there is a small high speed PCB in the OSA which provides a self layout place for the user; furthermore, the lower part is heat-dissipating device. In the design, data path is distributed at the shorter paths on both sides so as to effectively reduce the high speed effect of packaging and to make the high frequency critical path the shortest and the signal reflection the smallest and finally maintain the signal quality. The feature of butterfly OSA is that it is more suitable for edge emitting optical device. However, from the most updated trend in 2003, we can see many publications using TO as the OSA for 10 Gbps application with some even in the mass production stage. Taiwan suppliers can gradually catch up with the progress in technology and promote science project together with domestic legal entity to push the technology further upward and to further reduce the construction cost of 10 Gbps network.



（a）TO-can（資料來源：晶誼光電）



（b）Butterfly（資料來源：Agere）

Figure 1-5

Optical transmitter module contains an active component which performs E/O signal conversion, that is, Laser Diode (LD) and a Laser Driver; optical receiver module contains an active component for E/O signal conversion, that is, Photo Diode (PD) or called PIN Diode), a Transimpedance Amplifier (TIA) connected to the diode, and a Post Amplifier for further amplification of the voltage signal, this amplifier is mostly designed with limiting voltage and is thus called Limiting Amplifier. Next, optical transceiver chip set design technology will be discussed, here we only introduce general rule of design and no actual circuit design details will be discussed.

Optical transmitter chip is a driver for controlling light emitting device used in the transceiver for E/O conversion. Laser diode is commonly used as optical device in the high speed optical fiber communication network, therefore, the controller chip is generally called laser driver. The most important function of laser driver is to provide a current for controlling the light emitting of laser diode and the current/optical power conversion characteristic of laser diode is as shown in figure 1-6. The laser optical power has two conversion zones; one is the self-emitting zone below the transition point with not large optical power output, however, once it exceeds the transition zone, laser will start to be excited and the optical power will be greatly enhanced. Therefore, the control current for high speed laser can be divided into two types, one is the bias current which is used to make the laser stay at the edge of excited zone; another one is modulation current which is used to let the output optical power of the laser be in two data optical power energy levels of ”H” and ”L” according to the input data.

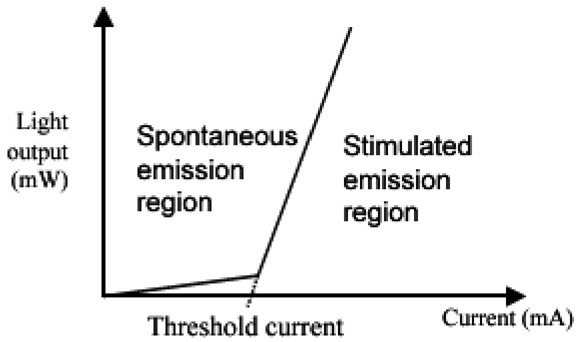


Figure 1-6

A standard laser driver contains a re-timing circuit data for input data so as to eliminate the jitter or distortion generated on the signal after it passes through PCB and I/O; it also contains a PWC (pulse width control) so as to adjust the signal pulse width and bias voltage/modulation current output circuit, etc.; this is as shown in

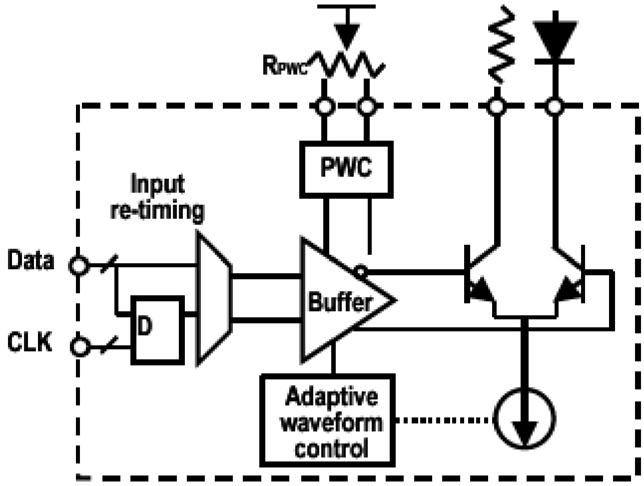
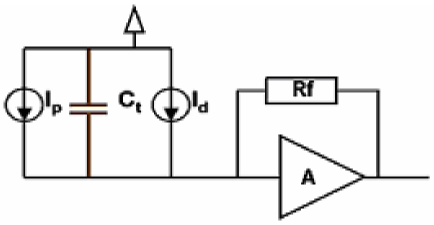


figure 1-7.

Figure 1-7

Generally, the current output capacity of high speed laser driver is about between 10mA to 100mA so as to match the need of different laser diodes under different environmental conditions. Since the laser driving current output has different amplitude, therefore, if it is not appropriately adjusted, overshooting phenomenon will appear on the current output. Thus, a buffer circuit is generally added in front of the current output and appropriate adjustment and modulation will be done based on the size of the output current in order to prevent the overshooting phenomenon generated on the output data. Of course, either single end or differential method can be adopted for the laser driver and current output. The chip on optical receiver end can be divided into two grades amplifier, the front grade is a transimpedance amplifier, which forms a optical receiver subassembly with the photo diode in charge of E/O conversion; its function is to convert the current signal converted from photo diode into analog voltage signal. Conceptually, transimpedance amplifier is composed of a high gain circuit accompanied with a feedback resistor which is as in figure 1-8. There are two important design parameters in transimpedance amplifier, they are, bandwidth and gain; the bandwidth will decide the maximum operable data speed of transimpedance amplifier, while gain (or called transimpedance) decides the sensitivity of the receiver.

Refer to photo diode circuit model of figure 7, the I/V transform function (gain) and -3dB frequency (bandwidth) of the transimpedance amplifier can be simply represented as in equations (1), (2):



$$G = \frac{AR_f}{1 + AR_f} \approx R_f \qquad (1)$$

$$f_{-3dB} = \frac{A}{2\pi R_f C_t} \qquad (2)$$

Figure 1-8

From the above formula, we know that gain is decided by feedback resistance (Rf) and the bandwidth is decided by the equivalent stray capacitance and feedback resistance at the input end; generally, the bandwidth is inversely proportional to the gain and is an important factor in the design. Generally speaking, if the data is encoded with NRZ (non return to zero), the bandwidth of transimpedance amplifier is constantly designed as about 0.7～0.8 times that of the highest data transmission speed in order to get optimum bandwidth/gain combination. Figure 1-9 is the functional block diagram of pre-amplifier at the optical receiver end, in addition to the core transimpedance amplifier, there is an AGC (auto-gain control) circuit to dynamically adjust the equivalent trans-impedance of amplifier in order to enlarge the acceptable dynamic range of this receiver circuit; the back side of transimpedance amplifier will be connected to several buffer amplifier so as to enlarge the output amplitude of the pre-amplifier at the receiver end and to enhance its sensitivity.

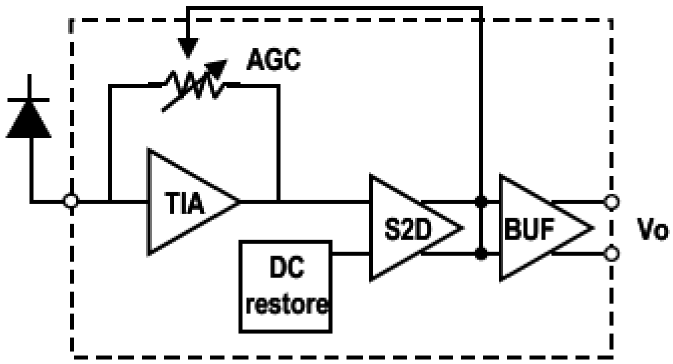


Figure 1-9

Transimpedance amplifier is connected directly to photo diode and is mostly single end circuit, however, in the network operation of high speed optical fiber communication, the receiver is mostly of differential output; therefore, after the transimpedance amplifier, a single-end-to-double-end circuit is used to convert the data path in the pre-amplifier at the receiver end into differential mode. The post amplifier at the receiver end is connected after optical receiving subassembly with a function mainly to amplify the differential voltage signal outputted from pre-amplifier to an output signal of stable amplitude. Since the main purpose of this amplifier is to output a signal of stable amplitude no matter what the input amplitude of post amplifier is, therefore, post amplifier is also called limiting amplitude amplifier. The core circuit of limiting amplitude amplifier is voltage amplifiers connected in series and the voltage amplifier is the basis for providing the gain of the limiting amplitude amplifier; enough gain is provided after several series connected amplifiers so that all the input signals can be amplified to certain amplitude and the output amplitude is controlled by the output bias current. In addition to basic series connected amplifiers, there are still some design keys in the limiting amplitude amplifiers: first is DC offset at the bias point; since high gain circuit is easily affected by the mis-match caused by process variation, which will in turn lead to differential output bias point drift and the difficulty in signal decoding, therefore, negative feedback DC offset cancellation circuit has to be added to automatically compensate the bias voltage error caused by asymmetricity in the device. The second is the loss of signal (LOS) detection needed in optical fiber communication system application; the main purpose is to inform the system there is no input signal at this time and appropriate action has to be taken, the reason for no signal might be caused by broken optical fiber or a loose coupling in the transceiver, etc.

Under the great promotion by Japan, the FTTH (Fiber To The Home) market in Asia Pacific area shows a bull head. PON (passive optical network) will be tomorrow's star in local area network or access network. Since PON uses high efficiency economic structure of BI-DI and single point to multi-point, it is thus the most effective communication method to connect to the end user of access network. The major difference between PON and conventional network is the change from a transmission of point to point (P2P) to a transmission of point to multi-point (P2MP); BI-DI structure is adopted, that is, passive optical device is used from the backbone to each end user and coupler or splitter beam splitting technology is used to divide from backbone to each end user; moreover, same optical fiber is used for uploading and downloading and two wavelengths are used to handle data of different directions (similar to BI-DI). Currently, ITU and IEEE have defined related network standards for PON, ITU has defined APON (ATM PON), BPON (Broadband PON) and GPON (GigaPON, G.984), etc.; in IEEE part, EPON (802.3ah) is defined by EFMA (Ethernet in the First Mile Alliance) and in the Supercomm meeting held on July 2004, EFMA announced that IEEE standard commission has recognized in all to use 802.3ah as the standard of "Ethernet in the First Mile", and the last name of the standard is 802.17, that is, Resilient Packet Ring standard. The transmission structure of point to multi-point is dominated by a headend, which is in data transfer to many users. Headend is called OLT (optical line terminal) and the user is called ONU (optical network unit), since the data path from OLT to ONU is of broadcasting method, there is thus not too much change in the technology; however, the path from ONU to OLT is time division method, each ONU transmits data only in its own time slot and OLT receives data from different ONU at each time slot which is as shown in figure 1-10. Therefore, the transmitter end of ONU and the receiver end of OLT are no longer of continuous modes; instead, they are burst mode of time slicing nature. The highest influential factor on the point to multi-point transmission is the E/O control IC in the transmitter module. It will affect ONU transmission end in a way that when data is only transmitted in the distributed time slot, only that time slot can trigger the laser and at other time, laser must be turned off in order not to affect data transmitted in other ONU in the optical fiber. Therefore, two changes must be performed, one is the turn on/off of the laser, that is, at time slot not transmitted by that ONU, the laser must be turned off in order not to affect other ONUs which are transmitting data; however, at the transmission slot of that ONU, laser must be turned on very rapidly. In order to let laser turn-on time be smallest, the status keeping of laser turnoff is thus very important, at this moment, the laser is not fully turned off, instead, the output power is kept below certain level as long as it does not affect other data in the optical fiber. Additionally, the adjustment data for tracking laser characteristic change due to temperature and aging effect should be preserved so that the laser can be turned on fast and correctly when time slot arrives. The faster the laser turn on/off speed (EPON requires this time to be <512 ns), the smaller the time slot division can be and the utilization rate of optical fiber or data throughput will be enhanced relatively. At the receiver end of OLT, the problem faced due to burst mode transmission can be studied in two aspects. One is the intermittent data packet; we know that in the receiver design, the DC value of data needs to be frequently acquired to stabilize the work point of analog circuit; therefore, coding is the usual way in communication to make DC balance on the data in order to stabilize the work point on the analog circuit at the receiver end. However, under the transmission mode of burst mode, DC balance will be destroyed in the intermittency of each time slot, therefore, when data packet gets in, if the work point of the circuit can not be recovered in fast way, data error or loss can occur. Another aspect worth of attention is the difference among different ONUs; since OLT receives data from different ONUs and since the distance of each ONU and the laser aging level at the transmitter end is different, therefore, the optical signal received will be different and the dynamic range of OLT receiver end should be designed relatively high in order to receive optical signal from different ONUs.

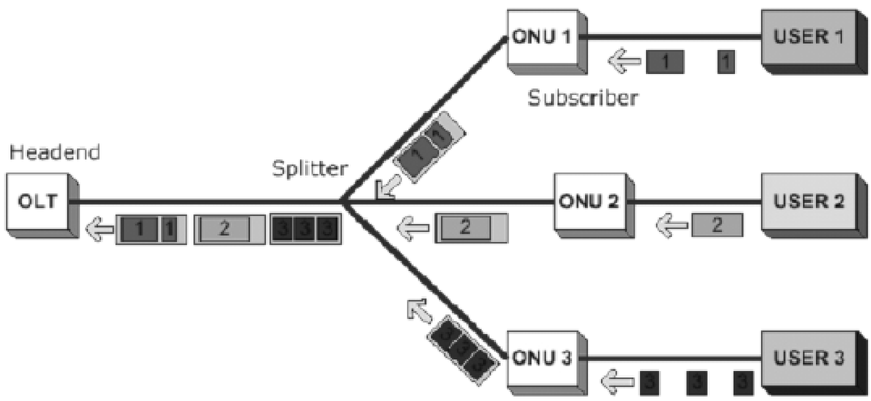


Figure 1-10

In Taiwan, there are not many optical transceiver manufacturers and it is as shown in figure 1-11 according to the upstream and low stream relationship of supply chain.

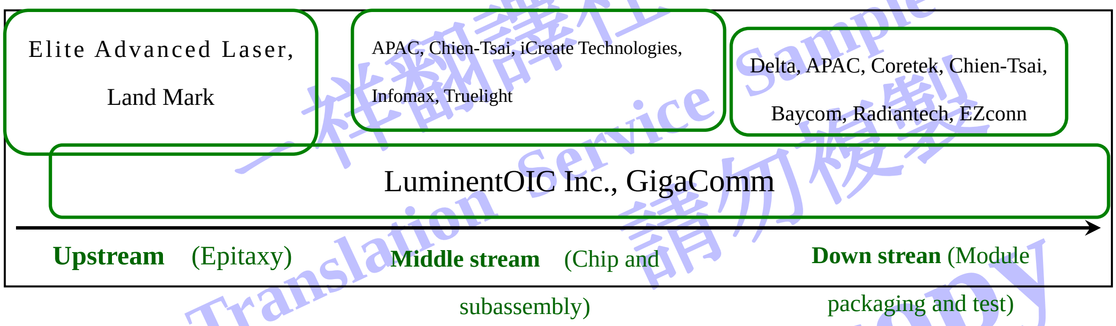


Figure 1-11

After understanding the physical structure of optical transceiver and its industry structure here in Taiwan, the next thing in this study is to perform a competitiveness analysis on Taiwan's optical transceiver industry with that of Europe, USA and Japan. Michael Porter's competitiveness analysis method is adopted in this study, three aspects such as: Focus, Differentiation and Price leader will be discussed respectively.

	Europe and USA	Japan	Taiwan
Focus	Good	Best	Normal
Differentiate	Best	Good	Normal
Price leader	Normal	Good	Best

Table 1-1

From table 1-1, we can find that the largest competitiveness of optical transceiver industry here in Taiwan is still only on price; based on this reason, if we want to let Taiwan's optical transceiver industry have more competitiveness, we need more job division in the supply chain and let each company only focus on its core technology; however, in the market differentiation part, we need to do it in two ways:

1. Urge the Taiwan government to enhance spec consensus for optical fiber communication system across the strait, so that, based on the stake from this market, Taiwan can be negotiating with Europe, USA and Japan for co-prosperity issue on the market.
2. Fully understand the market need of developing countries and use price superiority to gain the largest market share.