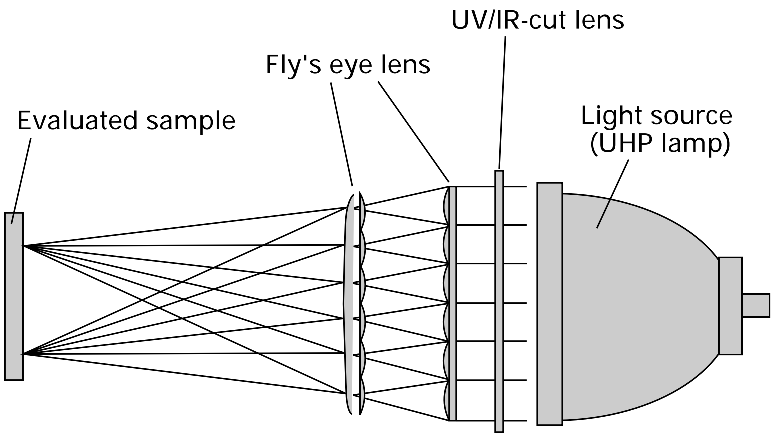

Fig. 2-33 Light exposure test system

2.4.10 Laser Diode (LD) Reliability

2.4.10.1 LD Failure

When laser diodes, which are light emitting elements, operate in the forward direction, the increase in current which does not contribute to light emission causes the light emission characteristics to change over time. Among these characteristics, the element life is generally defined by the time-dependent change in optical power output vs. operating current characteristics, which have a large effect on the drive circuit. This is shown in Fig. 2-34(a). When automatic power control (APC) drive which maintains a constant optical power output is performed, light emission at the constant optical power output P_0 is no longer possible at time t_5.

In consideration of the effect on systems using laser diodes, Sony defines the laser diode life as the time when the operating current becomes 1.2 times the initial value. (Fig. 2-34(b)) However, as shown in Fig. 2-34(a), this does not mean that the laser diode is no longer able to emit light.

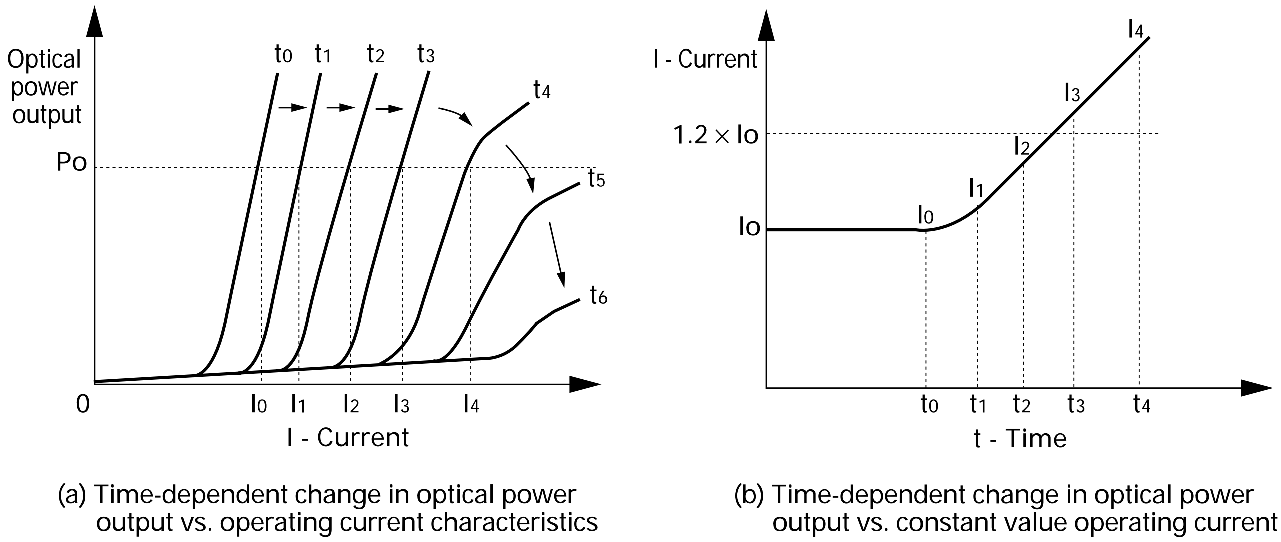

Fig. 2-34 Time-dependent Changes in Optical Operation Current Characteristics

2.4.10.2 Degradation Factors

Laser diode reliability is closely related to the operating temperature, and the degradation speed rises exponentially with the operating temperature (rise in drive current per unit time: $\Delta Iop/\Delta t$). This relationship can be expressed as follows.

$$\tau \propto \frac{\Delta Iop}{\Delta t} \propto \exp\left(\frac{-Ea}{kT}\right)$$

Ea : Activation energy (eV)
k : Boltzmann's constant (8.616×10^{-5}eV/K)
T : Absolute temperature (K)

Based on the relation between the temperature and drive current rise ratio, laser diode degradation is generally obtained at Ea ≒ 0.7 eV[1], so near room temperature the life drops to approximately 1/2.2 for a temperature rise of 10℃. Equipment sizes are becoming more compact, so sufficient care must be given to thermal design to suppress laser diode temperature rises. In addition, the degradation speed generally becomes faster at temperatures in excess of the specified operating temperature upper limit, so sufficient care must be given to extrapolation using Ea ≒ 0.7 eV in consideration of reliability. In this manner, degradation which determines the long-term life is called degradation in the gradual degradation mode, or wear degradation. This wear degradation accelerates as the optical power output increases. Therefore, use within the range of the specified upper limit optical power output or less is important for obtaining sufficient reliability.

Laser diode failure during use is often edge degradation caused by a surge current or overcurrent. In laser diodes, as the current is raised to increase the optical power output, at a certain point the optical power output drops suddenly and irreversible damage occurs. This type of degradation is also called catastrophic optical damage (COD), and occurs when high optical power output density operation causes momentary melting of a part of the laser diode edge and the formation of crystal defects. Semiconductor devices are generally susceptible to surge currents, and laser diodes with a high response speed of 1 GHz or faster and a low operating voltage of approximately 2 V in particular are damaged instantly by surges. This is an inherent failure mechanism of laser diodes. In order to avoid this COD failure due to surges, it is necessary to prevent even momentary excessive optical power output from being generated by a momentary overcurrent entering from the power supply or surges. In addition, even if a relatively weak surge is applied and there is little initial deterioration in the laser diode characteristics, this has been confirmed to shorten the operating life thereafter, so care should be taken.

Laser diodes also deteriorate and fail due to crystal defects. Perfect semiconductor crystals have structures with a regular atom arrangement, but actual semiconductor crystals have crystal defects which are non-conforming portions in the atom arrangement. In addition, crystal defects may also be produced by mechanical stress applied to semiconductor chips in the laser diode manufacturing process. These crystal defects inside laser diodes have non-light emitting properties, and the energy provided when the power is on is converted to heat instead of light. Dark line defects (DLD) are when a dislocation, which is a type of crystal defect, grows and expands while the power is on. These DLD expand and grow faster at larger current densities or higher operating temperatures, and can cause degradation or failure. AlGaAs laser diodes often experience laser diode degradation due to DLD at approximately 100 hours, and this is called degradation by the rapid degradation mode.

2.4.10.3 Methods for Estimating Life

The average life of laser diodes is generally expressed by the mean time to failure (MTTF) obtained from high temperature accelerated life test data and Weibull charts. The estimated average failure time at room temperature for compact disc laser diodes obtained using the average failure time and activation energy at 70℃ is one million hours or more, indicating sufficient reliability for practical use.

Life tests are conducted on element lots screened using fixed methods to confirm that elements satisfy the demanded average life and have no initial failures, and the relation between the cumulative failure rate and the drive time is investigated. Fig. 2-35 shows an example Weibull chart. The life prediction calculated using a degradation activation energy of 0.7 eV is shown by the dotted line. The plotted life data shows that the laser in this figure has a failure rate in the accidental failure (m = 1) range, and that the average life (MTTF) corresponding to the time for 63.2% of all test samples to fail is one million hours or more at room temperature.

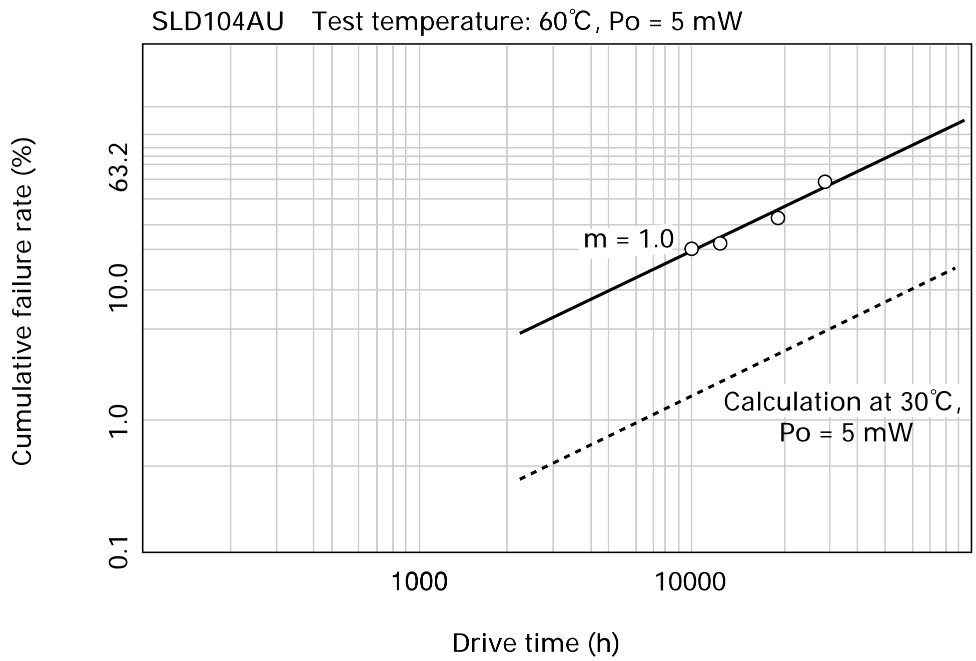

Fig. 2-35 SLD104AU Accelerated Life Test Results

2.4.10.4 Failure Analysis

When trouble occurs in laser diodes, an overall inquiry is made as to the cause by investigating the electrical and optical characteristics and observing the laser diode with optical microscopes and SEM, etc.

When current flows through a laser diode, the stripe portion emits light, and the cause of the failure is generally inferred by observing this emitted light. The observed positions are the laser diode edges which emit light, and the entire stripe portion which is observed by removing the photo-shielding electrode and semiconductor layers from the inside of the laser diode.

This section presents failure analysis methods using the light emission characteristics which differ from general semiconductor devices.

(1) Analysis of light emission at the laser light emission edges

Laser diode failure during use is often edge degradation due to a surge current or overcurrent. This degradation is also called catastrophic optical damage (COD), and occurs when high optical power output density operation causes momentary melting of a part of the laser diode edge and the formation of crystal defects. This melted portion absorbs light, so it is observed as degradation of the laser diode characteristics. When the operating current needed to obtain a certain optical power output increases (large Iop), the rated output is not produced, the laser diode does not oscillate, or an extremely large overcurrent flows, this is viewed as a failure such as current being unable to flow. Fig. 2-36 shows the device configuration for observing edge light emission.

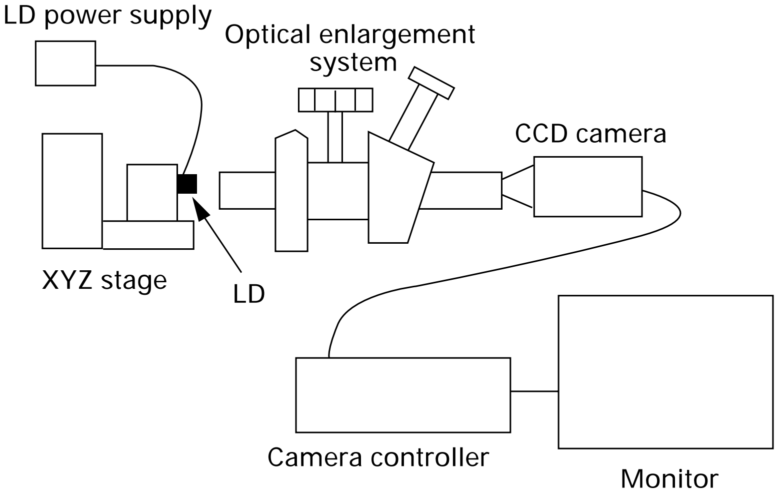

Fig. 2-36 Device for Observing Edge Light Emission

A low current of several mA is flowed to the laser diode to make it emit light, and the light intensity distribution at the light emission edge is observed (near field pattern observation). Normal laser diodes exhibit a Gaussian distribution as shown in Photo 2-21. During laser oscillation, the light density is highest in the center of the light emission area of the light emission edge, so crystal melting occurs in this location. Therefore, when the center of the near field pattern appears dark and forms a double peak or when the pattern appears divided into a number of peaks, this indicates that a surge or overcurrent has been applied and edge degradation has caused a light absorbing area near the center of the light emission area. (Photo 2-22)

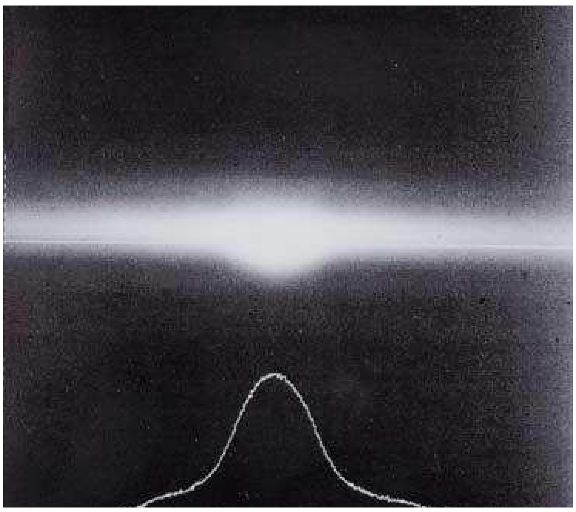

Photo 2-21 Normal Edge Light Emission Pattern

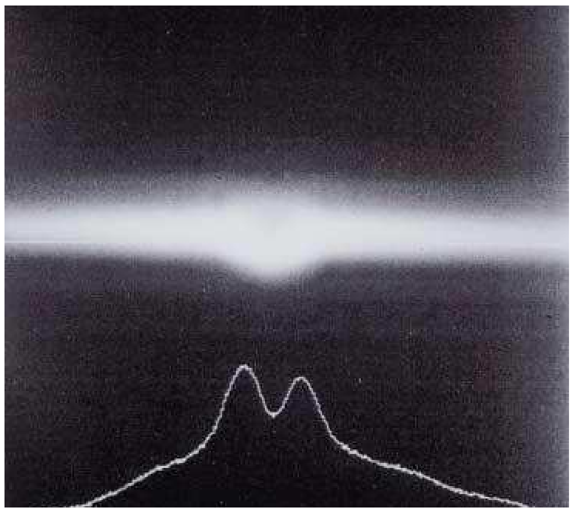

Photo 2-22 Degraded Edge Light Emission Pattern

2

(2) Analysis of light emission over the entire laser diode surface

For test samples where abnormalities are not visible by observing light emission from the edges or when defects occur inside the laser diode chip, the entire stripe must be analyzed. The cathode luminescence method allows observation of the entire stripe of failed laser diodes. This is done by removing the photo-shielding electrode and semiconductor layers using chemical etching to allow observation of light emission from the light emitting layer inside the laser diode chip. Then, the light emitting layer of the laser diode is made to emit light by irradiating it with electron rays instead of flowing current. If the emitting layer contains a DLD, this makes it possible to accurately know the DLD shape, orientation and resolution. Photos 2-23 and 2-24 show cathode luminescence images of a laser diode in which a crystal defect called a <110> DLD has formed near the edge. In addition, a faint <100> DLD can also be seen.

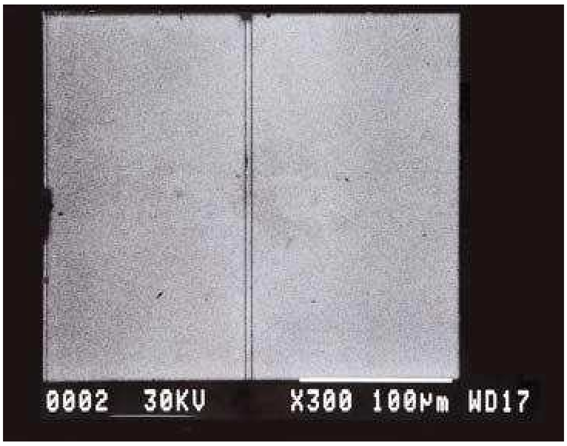

Photo 2-23 Cathode Luminescence Image of a Laser Diode with a Crystal Defect near the Edge

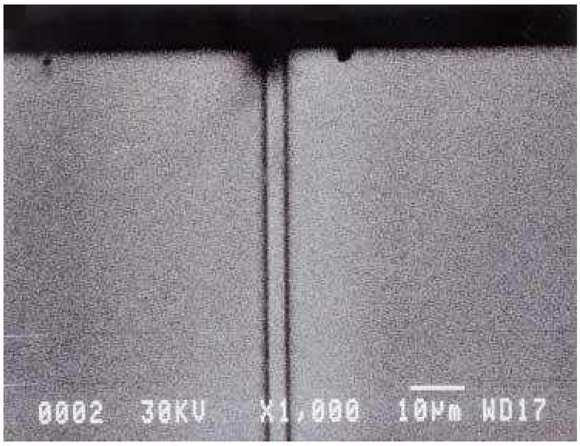

Photo 2-24 Enlarged View

<References>

1) R. L. Hartman and R. W. Dixon, "Appl. Phys. Lett. 26", pp.239-242 (1975).