Development of the FBT Laser Module with Adhesive Bonded Structure

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ABSTRACT To get a high performance and a high reliability, we had improved the miniaturization of modules and components on the FBT laser module, and then bonding these components with resin adhesive becomes essential to allow flexibility of its design. However, with respect to the usage of organic resin in the sealed package, outgas deposition in the optical components becomes a concern. Then, conducting analytical experiments which applied in the cases of high temperature condition over long periods or checking the existence of uncured resin, we proved that the deposition does not influence the reliability and it becomes possible to use resin adhesive. According to this result, we have developed the FBT laser modules which use the resin adhesive to bond the components, and achieved the high performances such as lower power consumption of 24% and higher optical output power of 15%.

1. INTRODUCTION

So far, we have produced the laser modules of the Full Band Tunable (FBT) and the Distributed Feedback (DFB) which are used in Dense Wavelength Division Multiplexing (DWDM) 1). With the expansion of communication capacity, to get the higher performance of the FBT laser module becomes an issue and, especially when low power consumption and high output power are important. As needed electric power is increasing with higher performance of the transmission equipments, the low power consumption of mounted devices including laser modules are required to reduce the needed electric power. Additionally, as multistage modulators are used with higher data transfer rate, higher output power of laser modules is needed to compensate insertion losses of the modulators.

To meet such demands, more appropriate optical and thermal design is needed more than ever. To achieve this, the increase of flexibility in selection of sizes or materials of components which are used in the modules is important. Additionally, miniaturization of the laser modules is getting more required because the transceivers or the transponders are being miniaturized, so that the miniaturization of the components will soon become essential.

In a conventional FBT laser module, as each component is fixed with soldering or yttrium aluminum garnet (YAG) laser welding, the components such as lens and etalon, which main material is glass or quartz are mounted in a metal holder. For this reason, the components including the metal holder are growing in size, and it limits their layouts and makes the optical path so long in its design. Therefore, as a method of fixing components to improve the flexibility of the design, we considered bonding of the components with resin adhesive.

Direct bonding of the components by resin adhesive allows miniaturization of the components because metal holders become unnecessary. In addition, conventional soldering requires the use of several solder materials to assemble the components, also, in descending order according to their melting points. However, the bonding with resin adhesive does not limit the order of assembling. Additionally, in YAG laser welding, materials of inner optical bench (base) need to be metal in addition to the metal holder, however, in adhesive bonding, it is possible to select ceramics which have high thermal conductivity and small linear expansion coefficient. It becomes possible to draw electric circuit patterns on this non-conducting base and then to simplify an inner electrical wiring. With such high flexibility of the design, the selection increases for components focusing on the high performances, the high reliability and the cost.

Having such benefits mentioned above, yet resin adhesive had not been used for bonding components in semiconductor laser modules. That is because the semiconductor laser modules are sealed with full-filled nitrogen gas and there is a concern about that outgassing from the resin adhesive may fill in the modules and influence

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the reliability.

Then, we designed and manufactured the FBT laser module with adhesive bonding structure and provided verification experiments of reliability especially focused on influences of resin.

2. FBT LASER MODULE WITH ADHESIVE BONDED STRUCTURE

2.1. The design of the FBT laser module with adhesive bonded structure

The FBT laser module with adhesive bonded structure is shown in Figure 1. The package is the butterfly-shaped package which is a standard in the industry. The optical beam of the LD is converted into the parallel beam by collimator lens and branched by a beam splitter (BS) into optical wavelength locker and main beam. To avoid the coupling of the reflected beam to the LD, an isolator is used. Photodetectors (PD) for power monitoring and for wavelength monitoring and an etalon of 50GHz cycles are mounted in the wavelength locker.

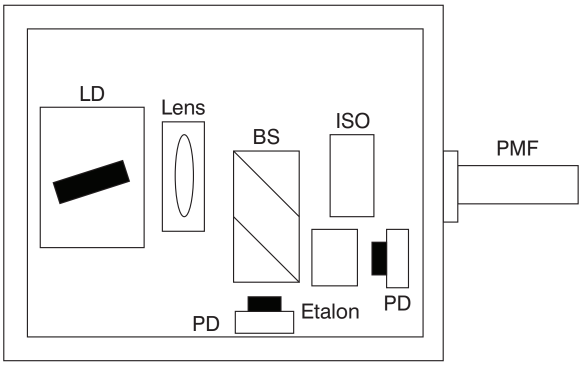


Figure 1 FBT laser module with adhesive bonded structure.

2.2. Selection of the resin adhesive

If ultraviolet (UV) curing resin is used, optical components which required high positional accuracy, such as lens, can be fixed as aligned. However, only with UV curing, there may be the case that the resin adhesive under the components is incompletely cured because the resin adhesive is shaded by the components, therefore we have adopted hybrid UV cure resin adhesive which is both UV and thermal curable. The components are fixed in their positions by UV curing right after their alignments and then completely cured by thermal curing. This heating is necessary both for annealing after the UV curing and curing by heating itself.

Epoxy is known as a base of resin adhesive which meets requirements such as its adhesive strength is high, has small dispersion and does not become weak with heat or light, and it has small shrinkage ratio and less outgas after curing 2). By contrast, acrylic adhesive is known that it often has higher shrinkage ratio and weaker adhesive strength than epoxy, and also silicone adhesive is known that it easily evolves outgas of low-molecular-weight components with heat. With all these factors, epoxy is superior as the adhesive for the precision optics in sealed packages; therefore, we adopt epoxy in our product.

2.3. Collimator lens

Conventionally, collimator lens is mounted in metal holder with YAG laser welding. However, we do not use metal holder because the collimator lens is bonded with resin adhesive. It is desirable that the shape of lens has a flat surface for easy mounting vertically. In order to adapt, the lens is typically shaped as a square pole in its simplest form, and also has a small size in length and width of 1 mm and depth of 0.6 mm or less according to characteristics such as beam's diameter and focusing distance.

The adhesive is an added inorganic filler to adjust the linear expansion coefficient. The linear expansion coefficient of materials for the components bonded is 0.5 to 0.6 ppm/K for quartz, 6.5 to 7.5 ppm/K for alumina or 4 to 5 ppm/K for aluminum nitride as compared to 100 to 150 ppm/K for epoxy, so that inorganic filler such as fine silica or fine talc is added to adjust the linear expansion coefficient to a smaller value.

However, if size of filler is large, it may become, as it is to be expected, a cause for the components to tilt. The worse condition of the components to tilt the most is when the filler is stuck under the component in the middle of its depth. Allowable tilt angle of collimator lens adapted this time is found to be 2 degree, according to the result of our experiment. Therefore, the allowable filler size x will be;

$$x = \frac{A}{2} \sin 2^\circ$$

where A is the depth of the lens. This relation is shown in Figure 2. Since we use the lens with a depth of 0.6 mm or less, we choose the 10 μm or less for filler size.

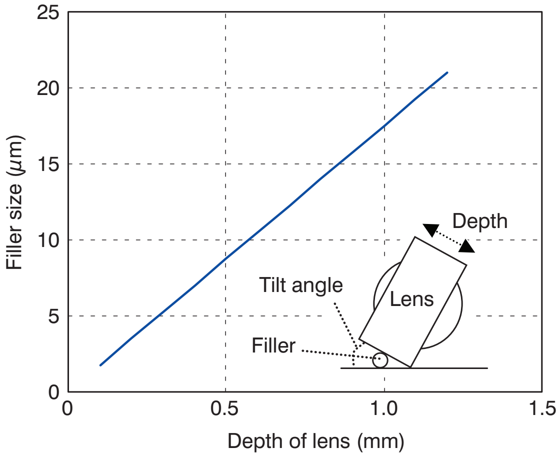


Figure 2 Allowable filler size to lens length.

2.4. Beam splitter

Wavelength locker consists of an etalon and PDs for power monitoring and for monitoring the light coming through the etalon of the wavelength filter. With the metal holder being eliminated and with the miniaturization of the isolator, etalon and beam splitter becoming possible with the use of resin adhesive, we reviewed the optical system and designed it as short as possible with respect to its optical path.

We select a triple-splitting beam splitter which has two splitting planes in parallel. Therefore, the main beam and the split beam are definitely split in parallel and the distance between the parallel beams is mainly subjected to the component accuracy of the beam splitter, so required positional accuracy in the beam splitter bonding is acceptable to be imprecise. For example, the angle of beam is stable even if the beam splitter is fixed on a tilt. Therefore, tolerability for angle shifted seems to be very high. Beam splitter shape and split beams are shown in Figure 3. As just described, we could construct the wavelength locker which has very high yield ratio toward the shifts of angle and position, and high long-term reliability.

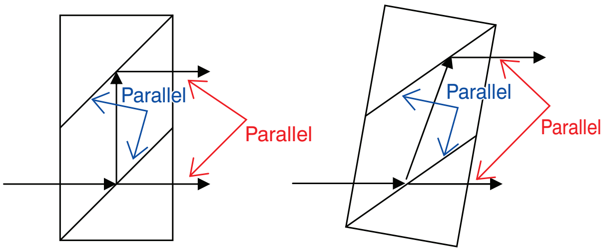


Figure 3 Beam splitter shape and parallelism of split beam.

3. CONDITION OF THE RESIN ADHESIVE AND ITS EVALUATION

3.1. Curing condition of the resin adhesive

The curing conditions with each UV and the heat of the adapted resin adhesive are confirmed by differential scanning calorimetry (DSC). The term DSC here is a measuring method that, while the UV irradiation or the heating is progressing by the heat sweeping method, the heat generation or the endotherm of the test piece is measured by measuring the temperature difference between the test piece and the reference specimen, and the reaction such as hardening of the resin adhesive is observed. In addition, after curing, when the resin is again irradiated with UV or heated up, and if the resin has no heat generation, the fact that the curing was completed with the first condition can be confirmed and that the first condition was sufficient.

First, to decide a tentative bonding condition, UV-DSC under four conditions with irradiation intensities of 30, 60, 100 and 200 mW/cm^2 are measured. The results are shown in Figure 4. For example, it is founded that, in the case with irradiation intensity of 100 mW/cm^2, the UV curing is completed within 26-second irradiation. Each irradiation intensity and the time of heat generation to complete are shown in Table 1. For this product, the irradiation of 100 mW/cm^2 × 30 sec is selected as the UV curing condition in consideration of dispersion.

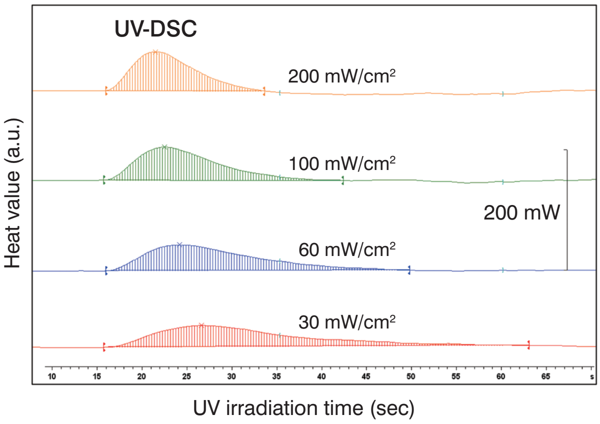


Figure 4 UV-DSC measured UV cure condition and heat value per unit weight.

Table 1 Time of heat generation completed in each irradiation intensity

Irradiation intensity (mW/cm^2)	30	60	100	200
Time (sec)	47	34	26	17

Next, for the thermal curing condition, to find out the temperature at which the cure phenomenon occurs, the heat generation fluctuation of the resin when it is heated is measured. The resin cured by UV is heated at 130°C for 10, 30 and 60 minutes, and then DSC measurements are taken on the resin over 25 to 200°C. As shown in Figure 5, the heat generation temperature increases with the heating time. The heat value is 140°C or more when the cure condition is 130°C for 30 minutes and 150°C or more when the cure condition is 130°C for 60 minutes. This indicates that the constituent that react on high temperature is remaining if heating time is insufficient. However, since the resin is not heated up to 150°C or more after curing, the condition with 130°C for 60 minutes must be considered as sufficient.

Similarly, DSC measurements are taken with the condition of 140°C and 150°C with variation of curing time, and the heat value per unit weight is shown in Figure 6. It is found that the curing is completed for around 10 minutes with140°C and within 10 minutes with 150°C. According to this, it is appropriate that the thermal curing conditions are 60 minutes or more on 130°C and 10 minutes or more on 140°C.

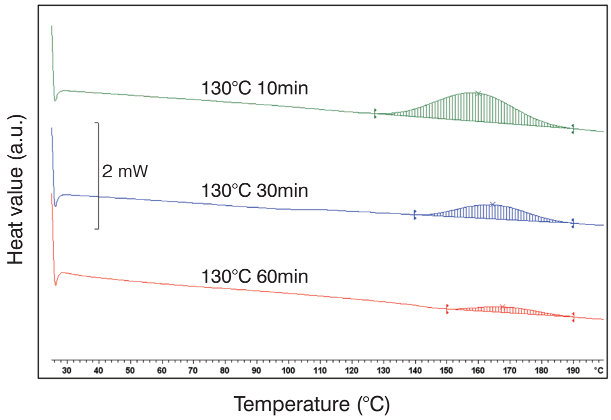


Figure 5 DSC measured 130°C cure condition.

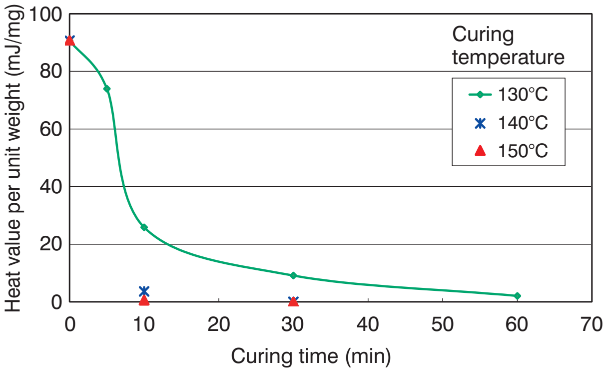


Figure 6 DSC measured thermal cure schedule and heat value per unit weight.

Next, assuming the case of incomplete UV curing, the DSC measurement is taken on the resin without UV curing to see the curing condition of the resin only with heating. As a result, the heat generation is observed and curing phenomenon is confirmed without tentative UV bonding. As DSC measurement is taken again on the same test piece, the heat generation is not observed and it was found out that the curing can be fully completed only with heating. The result of the DSC measurement is shown in Figure 7. According to this, it is found that the resin adhesive will be completely cured only with heating even if the resin adhesive has partially been unexposed to UV because of shade of the components.

As described above, we examined by DSC and decided the curing condition of resin.

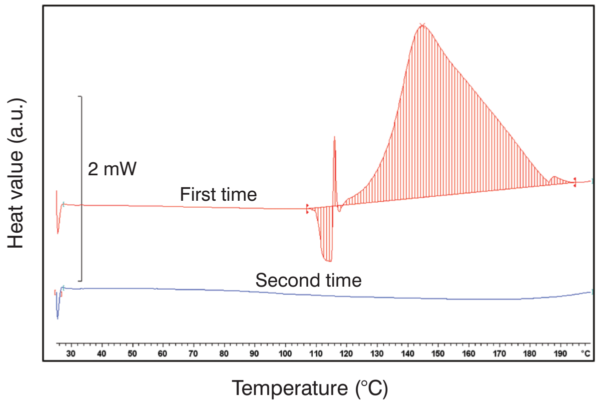


Figure 7 DSC measured thermal cure condition without UV cure.

3.2. Analysis of outgas

The previous issue of most concern with use of resin in sealed package is outgas. Amongst the concerning issues that have come up is: after the package is sealed, gas is generated from the curing resin with the variation of environmental temperature or irradiation of laser beam; this gas gives negative effects to the surface of the laser and makes the laser lifetime shorter, or the outgas deposits and solidifies as a kind of film forming on the optical components and, thus, the optical characteristics are changed. Therefore, we analyze outgas from the resin after curing.

A certain amount of curing resin is trapped and sealed in a glass vial container and left out in 85°C for 2000 hours. This gas in the vial container is analyzed by headspace gas chromatography mass spectrometry (HS-GC/MS). The analysis of items covers the type of outgas and its amount. For the amount of the outgas, its semi-quantitative value is worked out by toluene based conversion from chromatogram detected by a mass spectrometer. The reliability of FBT laser module needs to be proved as high enough under temperature range of -40 to 85°C according to Telcordia Standards. However, as the outgas from the resin increases with temperature increasing, we adopt the leaving temperature of 85°C which is the highest temperature guaranteed, as a condition of the analysis.

According to the result of the analysis, the outgas for 2000 hours is in minute amount of 0.2 to 0.3 ppm and the amount of gas in the vial container is almost saturated in 500 to 1000 hours. According to that, even though a part of constituents in the resin generate outgas, it can be said that the outgas generation is over relatively in a short time and does not continue for long period.

In addition, the outgas is an organic matter and not caustic and film formability constituents is not included. Comparing the outgas constituents with base materials, it is found that the outgas constituents are resolution residues of the solvents or the hardener of each materials in the resin.

3.3 Influence of LD optical illumination

The possibility of alteration of the resin or outgas generation is of concern when the chemical reaction occurs on the resin with LD optical illumination. Therefore, absorbance of the resin in long wavelength range is measured and its absorbance spectrum is shown in Figure 8.

As optical absorbance is measured with the wavelength over 900 to 2000 nm, its maximum value is 0.5% with 1551 nm, the possibility of the chemical reaction or heat generation seems unlikely to occur because most of the optical beams are transmissive.

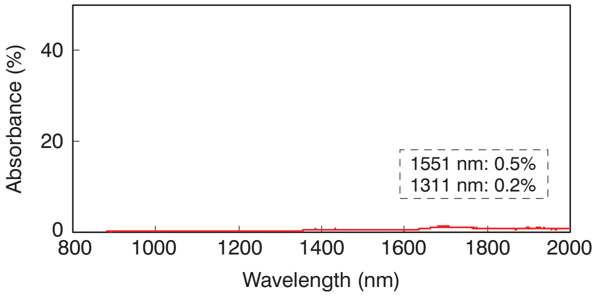


Figure 8 IR absorbance spectrum of adhesive.

Conversely, the possibility that the ultraviolet rays are contained in the optical beam from the LD is a concern. Therefore, short wavelength spectrum of LD optical beam is measured and shown in Figure 9.

Since the UV cured wavelength of the resin is around 360 nm and since the value of the LD optical beam of about 360 nm is smaller than threshold value with no obvious peak observed therefore, the LD optical beam does not likely influence the resin.

3.4. Influence of the outgas from the resin to the module performances

As the result of the analysis regarding outgas described in the section of 3.2, we made experiments and confirmed whether the resin has influence in practical matter use in the module package. The reliability test for the module is performed after the actual used resin of 10 times the amount is dropped in the package and then the module is sealed. In this experiment, the influence of the reliability can be verified the case that residues of solvent or hardener of materials which did not evaporate in the resin are present in large amounts. This has been done because it became obvious that the constituents of outgas consist of residues of solvent and hardener of materials.

After applying the actual used resin without curing and sealing, the resin is cured in the sealed package at 130°C for 1 hour. It can be verified that outgas which comes from the uncured resin and which occurs in curing in the package gives negative effects to the surface of the laser and makes the laser lifetime shorter, or if the optical characteristics become degraded because the gas has condensation or solidification when cooling down to lower temperature than the curing of 130°C and makes deposits on the surface of the optical components.

The aging test of the module which is filled with outgas and driven on the 75°C for long terms is performed and the output trend is shown in Figure 10. The output hardly varies during 2000-hour aging test.

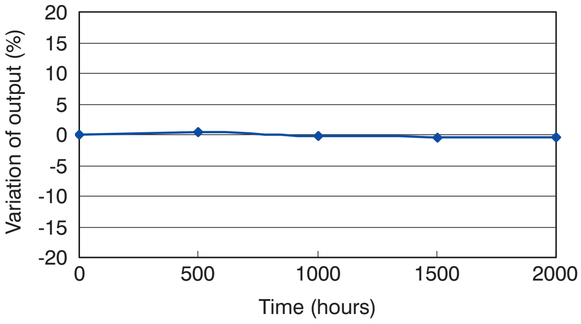


Figure 10 Output power trend in 75°C aging test of outgassed FBT module.

In addition, the surface of LD after 2000-hour aging test is observed. No deposit is confirmed by the observation with a scanning electron microscope (SEM), and also no condensing of elements such as carbon (C) on the light emitting section is confirmed by auger electron spectroscopy. SEM images and auger map are shown in Figure 11.

According to the above, even though outgas occurs, it has no serious influence on the reliability of LD and the module.

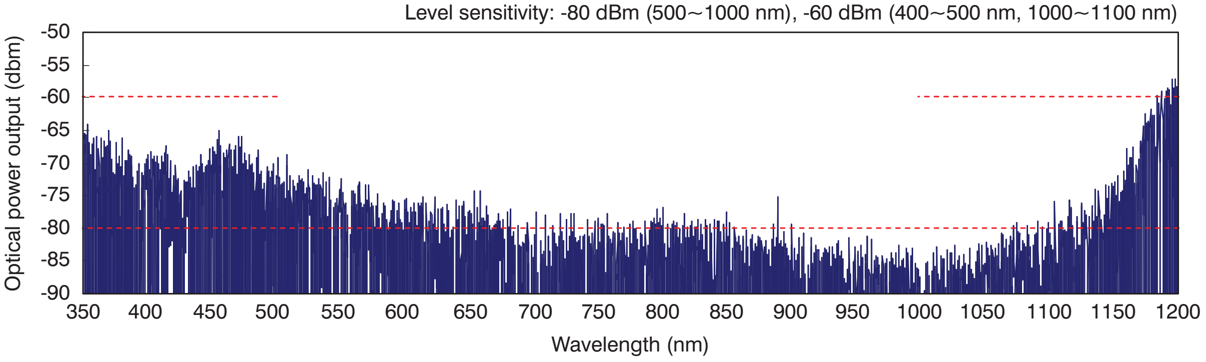
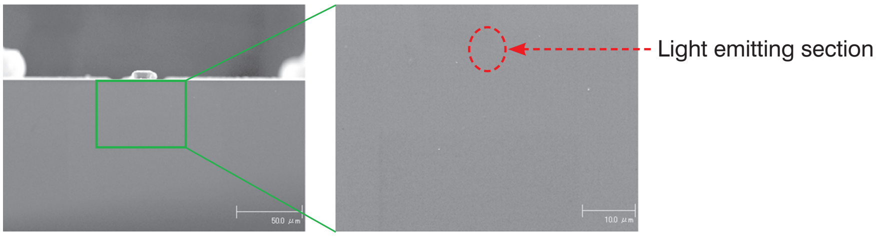
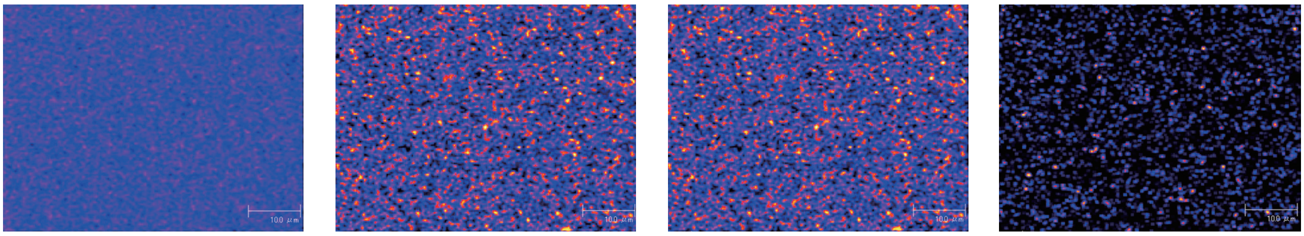


Figure 9 UV spectrum of FBT laser light.



SEM image of Measurement site SEM image of Measurement site



C Map O Map N Map Si Map

Figure 11 SEM micrographs and Auger maps of aging tested LD.

4. PERFORMANCES OF FBT LASER MODULE WITH ADHESIVE BONDED STRUCTURE

According to performances of FBT laser module with adhesive bonded structure, power consumption and optical output power as conventional issues are shown.

First, power consumption is shown in Figure 12. For example, when the optical output power is 10 mW, the power consumption of the module with adhesive bonded structure is 1.54 W comparing to the conventional module of 1.92 W and that represents a 20% reductions. When the power is 40 mW, the power consumption is 2.02 W of adhesive bonded structure comparing to 2.64 W of the conventional and that represents a 24% reductions. That is because, as adopting the resin adhesive technique for bonding of the components and wider options in the selection of component's materials, it becomes possible to use the materials with high thermal conductivity and therefore the power consumption is reduced.

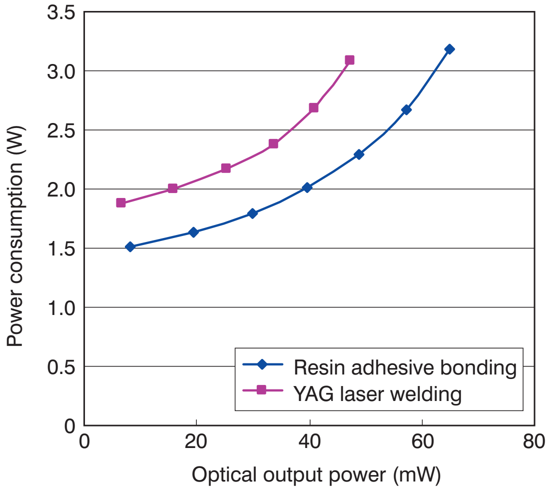


Figure 12 Power consumption of FBT modules.

Next, the results of the optical output power measurement are shown in Figure 13. For example, when current value of an amplifier is 150 mA, the optical output power of the module with adhesive bonded structure is 25.4 mW comparing to the conventional module of 23.3 mW and this is 9% improvement. When current value is 300 mA, the output power is 49 mW of adhesive bonded structure comparing to 42.8 mW of the conventional and this is 15% improvement. That is because, with miniaturization of the components, the structure can be optimized for optical coupling and the increase of the optical output power becomes available.

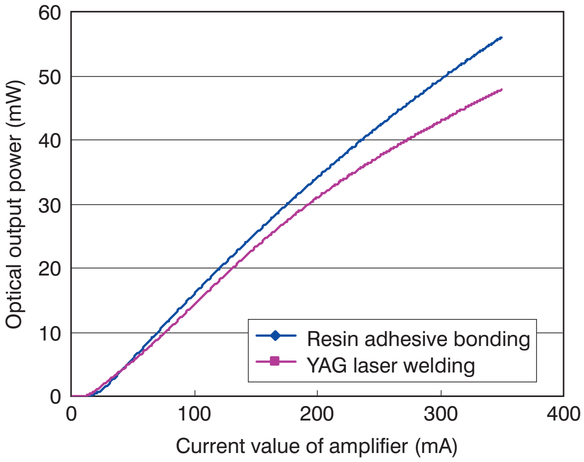


Figure 13 LI characteristics of FBT modules.

By adopting the resin adhesive bonding structure, we have achieved the FBT module with a high performance of low consumption power and high output power.

4. CONCLUSION

We have developed the FBT module which uses resin adhesive for bonding of components to achieve components' miniaturization and flexibility in selecting components' materials.

Since the degradation of the module reliability by outgassing over long period storage of the resin in the package is of concern, the results of the analytical experiments, despite the slight outgas is confirmed in early stages, reveal that the generated amount of outgas is saturated in short time and it does not continue generating, no influence is found on the long-term-characteristics of the FBT module and the surface of LD. Therefore we adopted the adhesive bonding. As adhesive bonding is adopted, the flexibilities on the module design are greatly increased and the performances of the module are highly improved. The power consumption is reduced by 24% and the optical output power is improved by 15%.

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