A Narrow Linewidth Tunable Light Source with an Etched Core DR Laser

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ABSTRACT A narrow spectral linewidth is required for both the signal light source and the local oscillator light source in a digital coherent communication. The use of a DR laser with a combination of a conventional Distributed Feedback (DFB) laser and a Distributed Bragg Reflector (DBR) mirror shows promise for improving the characteristic of the spectral linewidth. We devised a configuration employing an etched core type DBR for a DR laser, where an active layer as a waveguide core is periodically etched. We have achieved a line-width of less than 150 kHz by applying this etched core type DR laser to the laser part of a wide wavelength tunable light source.

1. INTRODUCTION

In these days, when many people use Social Networking Service (SNS) which can connect individuals on the network and contents such as Video On Demand (VOD) are provided on a telecommunication platform, the transmission speed increment becomes more important than ever before to convenience to the society. In a trunk part of telecommunication, the optical communication by digital coherent transmission is used. The digital coherent transmission is the technique that performs telecommunication using phase states of the wave nature of the light. Using this technique, the sensitivity of the telecommunication improves and also it becomes possible to use multilevel modulation format with a combination of amplitude and phase. Therefore it contributes to an acceleration of the telecommunication speed.

It is possible to increase the amount of information per character by increasing multilevel of modulation. For example, the transmissions of 2bits per character with Quadrature Phase Shift Keying (QPSK) as a 4-level phase modulation, of 4bits per character with 16 Quadrature Amplitude Modulation (16QAM) as a 16-level amplitude phase modulation, of 6 bits per character with a 64 Quadrature Amplitude Modulation (64QAM) as a 64-level amplitude phase modulation are possible. When the multilevel is increased as such, small noise degrades an error rate of telecommunication because the distance between each character becomes smaller.

In the digital coherent transmission, two lasers, called a signal light source on the transmitting side and a local oscillator light source on the receiving side, are used. Amplitude and phase are added to the signal light source, and a signal is transmitted and interfered with the light of the local oscillator light source on the receiving side, so that the amplitude and the phase can be demodulated. If the light phase of these two lasers sways, that becomes a phase noise of the signal and causes an error. For this reason, these lasers require a high frequency stability because the time differential of the phase is the frequency and the phase stability has a one-to-one relation with the frequency stability. An index showing this frequency stability is a spectral linewidth and the narrower the linewidth is, the higher the frequency purity is and the better the characteristic is.

We have already commercialized light sources with narrow linewidth for the purpose of a digital coherent transmission[1), 2), 3)]. Nowadays, it is a common case that a wavelength tunable light source, which can select and perform with the arbitrary wavelength within the communication band, is used as the light source for the trunk telecommunication on the assumption of a wavelength multiplexing. For this reason, these narrow linewidth light sources are designed to have functions of variable wavelength and are mounted onto the wavelength tunable laser module with a control circuit, which is called Integrable Tunable Laser Assembly (ITLA) or micro ITLA for its miniature edition (Figure 1).

Figure 1 Photograph of micro ITLA.

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For multilevel of transmission systems, a narrower linewidth than ever is required. Therefore, we have utilized the configuration called the Distributed Reflector (DR) laser as the laser which can achieve narrow linewidth, and applied it to the wavelength tunable light source[4]. We report the design of the DR laser and the characteristics of the wavelength tunable light source in this paper.

2. DR LASER USING AN ETCHED CORE TYPE DBR

2.1 General Concepts of a DR Laser

A DR laser is the configuration proposed at first by Tokyo Institute of Technology[5] and is the combination of a Distributed Feed-Back (DFB) laser and a Distributed Bragg Reflector (DBR) mirror.

A DFB laser is a configuration which has diffraction gratings in the active region of a laser. In a DFB laser, the bandwidth called stopband, where the light is reflected, is formed in the wavelength corresponding to the period of the diffraction grating and the laser oscillation occurs in that neighborhood. To have a stable single mode oscillation at the desired wavelength, a phase shift which matches each of the phases of reflections is necessary, and then, a configuration called $\lambda/4$ shift configuration where the phase shift is located near the center of the laser is often used. The output light of the DFB laser with $\lambda/4$ shift configuration is front/back symmetric, and so the light emitted backward becomes useless because it can't be normally used (Figure 2, top). On the other hand, it is possible to achieve a single mode oscillation not only by the $\lambda/4$ shift configuration but also by using a phase shift which occurs between a mirror reflection using a high reflecting coating of the back end face and a reflection of DFB without a phase shift. In this case, the front/back asymmetrical output light can be obtained. However, the reflection phase at the end face is determined not by a wafer process but by a cleavage. Therefore, it is substantially impossible to control the phase while manufacturing and the design of the phase shift value will be determined stochastically. Although it is possible to select the one which has good characteristics after manufacturing for a single laser chip, it is difficult to adopt the configuration where defective products occur stochastically to integrated devices which integrates multiple devices.

For a DR laser, DBR mirror is placed backward in the DFB region (Figure 2, bottom). Although the DBR mirror has a configuration with diffraction gratings the same as in the DFB, it is not an active region for the light emitting but it is a passive region where no current is injected. Using the DBR mirror which can be made not by a high reflecting coating at the end face but by a wafer process, a high reflecting mirror can be placed on the back end face with a fixed design. Therefore, with the DR laser, better characteristics than the DFB laser with a $\lambda/4$ shift configuration can be achieved with a high yield ratio which is suitable for integrated chips.

To make a laser with a narrow linewidth, as described later, it is necessary to make the threshold gain of the laser smaller. For the DFB laser, the optical distribution is exponentially decreasing around the phase shift, and the degree of this decrease becomes larger if the value called the coupling coefficient κ of the diffraction grating becomes larger. For this reason, if the product of the coupling coefficient and the length, κL, becomes larger, it is possible to make a light distribution at the edge smaller, to make an equivalent reflection ratio higher and to decrease the mirror loss. However, if κL becomes excessively large, the light distribution of the desired mode becomes drastic and a mode which causes a laser oscillation only in the region far from the phase shift occurs and the single mode property becomes worse. Therefore, κL has an upper limit to keep the single mode property.

On the other hand, with the DR laser, a forward equivalent reflection ratio can be determined similar to a DFB laser, where a backward reflection ratio can be determined by the DBR mirror. Even if the upper limit of κL is same as the one of the DFB laser, it is possible to make the mirror loss smaller because backward can use a high reflection ratio of the DBR mirror. For this reason, the DR laser shows promise for the narrow linewidth.

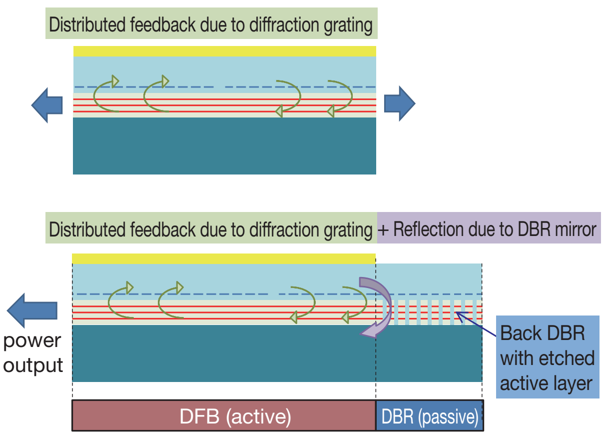

Figure 2 Schematic of a DFB laser (top) and a DR laser (bottom).

2.2 DR Laser Using an Etched Core Type DBR

The configuration of the DR laser proposed this time is shown in the schematic of Figure 2 (bottom). A characteristic point is that an etched core type DBR with a periodically processed waveguide core which is identical to an active layer is used for the DBR mirror. A clad material of InP is embedded into the part where the waveguide core made of GaInAsP is removed by etching. On the other hand, the DFB region where current is injected has, similarly to the conventional DFB laser, a continuous active layer as a waveguide core and has a diffraction grating in the neighborhood.

In this configuration, the waveguide core with the periodical configuration itself performs as a diffraction grating for the DBR. The coupling coefficient κ of diffraction grating in the DBR region can be greatly increased by a large refractive index difference between the core material and the clad material. Therefore, a high reflectance can be obtained with a short DBR and also a reflection band can be wider.

Since the DR laser has a large difference between the configurations of the DBR region and the DFB region, a suitable manufacturing process is required (Figure 3). First, the active layer and the diffraction grating in the neighborhood are formed uniformly in the plane by a crystal growth. And then, periodical patterns of both the DFB region and the DBR region are patterned by lithography at the same time. Using this mask pattern, the diffraction grating layer is etched by a shallow etching. In this step, the diffraction grating in the DFB region is etched periodically. Then, only the DFB region is covered and protected by another mask, and the DBR region is additionally etched. Having this additional etching as deep as it reaches the active layer, the etched core is formed in the DBR region. The process after removing of the masks and embedding InP is the same as conventional manufacturing process. Since the patterns of the DFB region and the DBR region are formed at the same time in this manufacturing process, there is no phase shifting between them.

A DR laser consisting of an active layer by periodical etching is studied by Tokyo Institute of Technology[6]. The differences from our proposed DR laser for now are that the DFB region has a continuous active layer and GaInAsP of the core material is not formed on the top after embedding.

Adopting the design of a DFB with a continuous active layer, which results in largely different configurations between the DFB region (consecutive active layer) and the DBR region (etched core), is a necessary configuration to design a DR laser with a narrow linewidth. For the DR laser, since the current is injected only into the DFB region, the refractive index variation due to the heat generation with the current injection mainly occurs only in the DFB region. Therefore, the refractive index difference between the DFB region and the DBR region in accordance with the operating condition easily occurs. For this reason, it is preferred that the reflection band of the DBR region is made wider to obtain a good reflection even if the wavelength characteristics of the DFB and the DBR differs by the refractive index variation. For that, it is useful to make the DBR as an edged core type. On the other hand, it is preferred that the DFB region is as long as possible. That is because, under the limitation of κL to keep the single mode property, it is easy to obtain a low threshold gain for a narrow linewidth if the DFB region is long. It is necessary to make κ lower to some degree to keep κL constant with long configurations. Therefore it is required to make κ of the DFB region much lower than that of the DBR region, and using not an etched core type but a diffraction grating in the neighborhood of the core has an advantage. Considering the characteristics required for both the DFB region and the DBR region as described above, it is necessary to divide the configurations of the DFB region and the DBR region for use as a narrow linewidth laser.

The reason of that the core layer is not formed after embedding the DBR is as follows. If the core material is formed on the top after embedding in the previous described manufacturing process, a similar layer will be formed in the neighborhood of the diffraction grating of the DFB region, as is unfavorable. Herewith, the DBR region becomes purely an etched core type DBR where no waveguide configuration exists in the low refractive index part. Therefore, the DBR design becomes different from the case where the core is formed on the top after etching. We will describe this DBR design in the next section.

2.3 Reflection Characteristics of an Etched Core Type DBR

The etched core type DBR has a configuration where the areas where waveguide core exist and do not exist are placed alternately in a longitudinal direction. Therefore, it is expected that the optical characteristic is different from the one of the configuration where the diffraction grating is placed in the neighborhood of consecutive waveguide cores.

In the case of the diffraction grating in the neighborhood of the core, the influence to the waveguide mode due to the existence of the diffraction grating is slight. Therefore, the difference between refractive indexes of waveguide modes with and without the diffraction grating layer can be described as two mediums which have different refractive indexes and are placed alternately in a longitudinal direction, and the optical characteristic can be calculated by using one-dimensional analytical methods. Amongst one-dimensional analytical methods, there is the method of the coupled mode theory and the discrete method[7), 8)]. The former manages the optical cou-

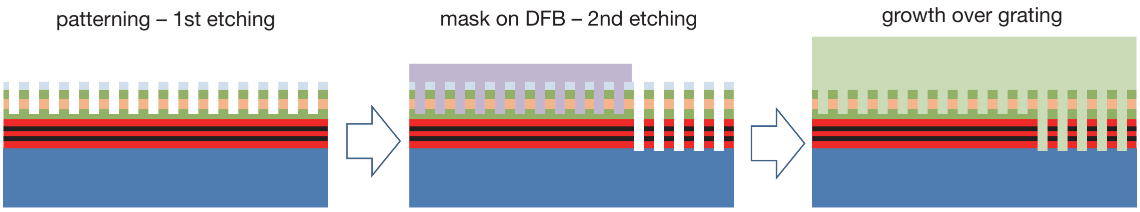

Figure 3 Manufacturing process of diffraction grating of DR laser.

pling of the lights propagating forward/backward by periodical perturbations of the refractive index, where the previously described coupling coefficient κ, shows the coupling strength in this coupled mode theory. The management of the diffraction grating by the coupled mode theory is often used for designing the DFB laser, and the designing of laser configuration becomes easier by using this method for the DR laser made of the DFB and the DBR in combination. The latter calculates an aggregate of a Fresnel reflection at the interface of different refractive indexes and is often used for designing a multilayered DBR. Compared to the former, the latter has the advantages that it can easily manage an arbitrary configuration and is appropriate for large refractive index difference, while the amount of calculation is increased because all reflecting points are considered.

These one-dimensional analytical methods cannot reflect the configurations of other directions except the longitudinal direction. To reflect the existence of a low refractive index part where no waveguide core exists, which is unique to an etched core type DBR, a multidimensional analysis is required. Therefore, we calculated the reflectance here by using a two-dimensional Finite Difference Time Domain (FDTD) method[9]. A FDTD method is a method that makes finite difference calculation on Maxwell equations and sequentially calculates directly, and it can calculate optical characteristics of any configurations without postulates and is effective especially for analysis including reflections. A waveguide configuration of a semiconductor laser has a configuration less than a wavelength in the direction of the thickness but a configuration about several times of wavelength in the direction of the width. Therefore, we calculated in two dimensions of longitudinal and thickness direction, ignoring dependency in the width direction.

A part of numerical model around structural interface is shown in Figure 4. The left half of the figure is the continuous waveguide which corresponds to the DFB region (but the diffraction grating near waveguide is not included in the model of this calculation) and the right half is an etched core type DBR. The pulse excitation is performed at the left end of the calculating region, and the electric fields of the first input pulse and the reflected pulse which has a time delay to the input pulse are observed in the continuous waveguide. Since both can be separated temporally, reflectance can be obtained by applying Fourier transformation on each electric field and calculating ratio of them (square of them, in the case of power calculations).

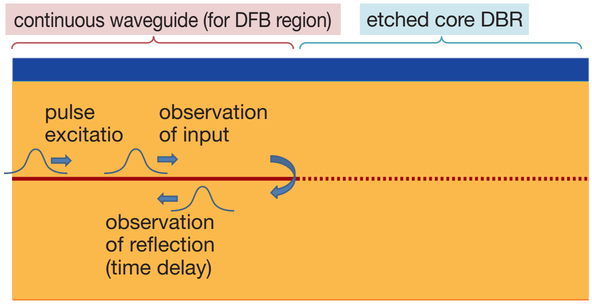

Figure 4 Calculation model of the DBR reflection by 2D-FDTD.

The calculation result of the reflectance in the case without absorption loss is shown in Figure 5. The length of the DBR is 300 μm. From this result, the reflection band of the DBR is definitely seen, and it is found that the reflectance is not symmetric with respect to the wavelength such that it is lower with the decrease of the wavelength. Usually, if there is no absorption loss, a symmetrical reflection about the wavelength can be obtained in the one-dimensional calculation. Therefore this information can be obtained in the two-dimensional calculation.

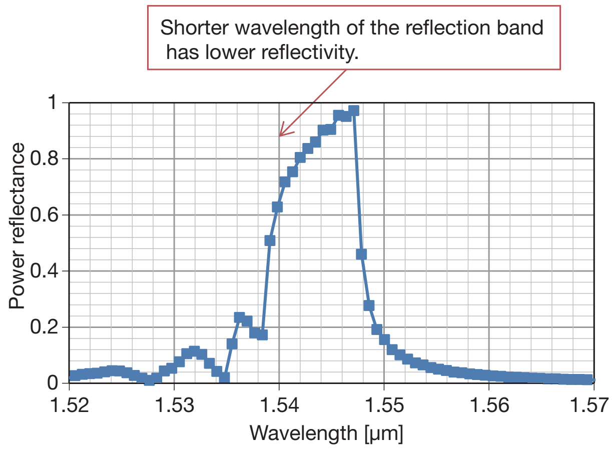

Figure 5 Reflection spectrum by 2D-FDTD.

To consider the cause of this asymmetrical reflectance about the wavelength, the space distributions of the electric field outputted with excitation in a CW (continuous light) is shown in Figure 6. The excitations were performed by corresponding frequencies on each longer wavelength band with a high reflectance and a shorter wavelength band with a low reflectance. The same region as the figure of the numerical model shown in Figure 4 is cut out, and the beginning point of the DBR is in the center of the figures.

From this figure, it is found that the light is injected into the etched core type DBR without loss in the longer wavelength band while there is large scattering loss at the DBR interface in the shorter wavelength band. That is, a longer wavelength band has a high reflectance because of a low loss and a shorter wavelength band has a low reflectance because of a high loss.

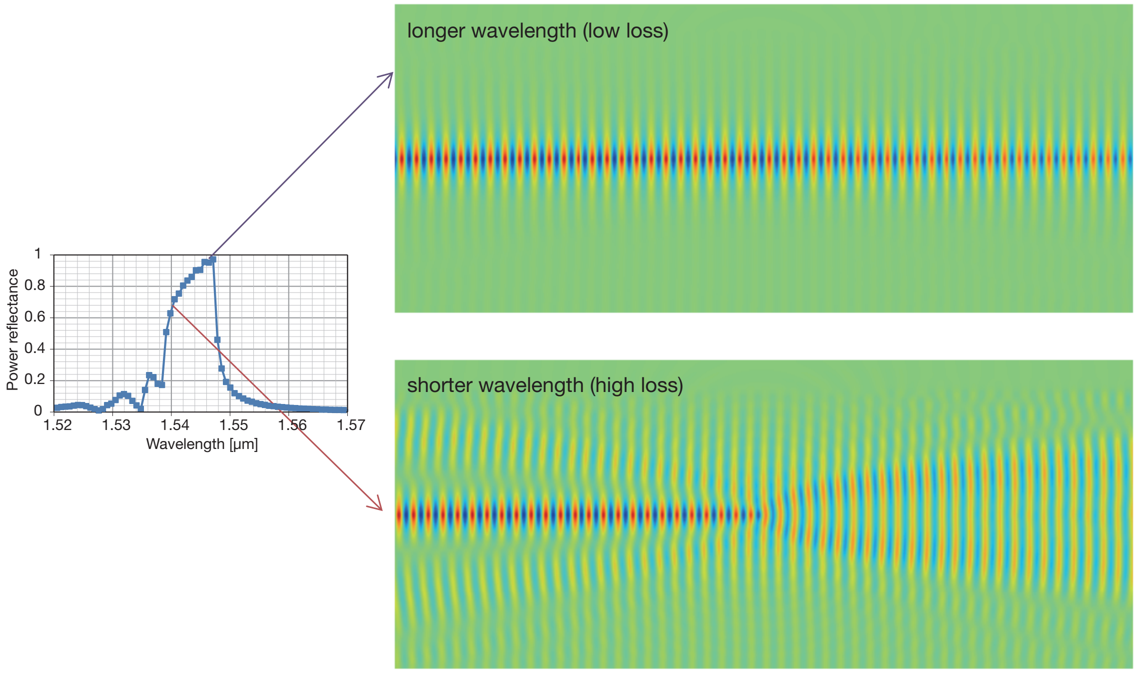

Figure 6 **Electric field around the DBR interface at the longer wavelength region and the shorter wavelength region of the DBR reflection band.**

This phenomenon can be explained as follows. Wave number in the direction of the propagation is fixed nearly to the Bragg wave number within the reflection band of the DBR. Therefore, the mode refractive index becomes high if the frequency is low (wavelength in vacuum is long), and it becomes low if the frequency is high (wavelength in vacuum is short). This is related to that standing wave is placed at the high refractive index area of the DBR when the frequency is low and standing wave is placed at the low refractive index area of the DBR when the frequency is high.

If the refractive index is high, confinement of light in the vertical direction of the waveguide is near to the continuous waveguide, and the consistency of the mode shapes in the continuous waveguide and the DBR becomes high. On the other hand, if the refractive index is low, the confinement of the light in the vertical direction of waveguide becomes loose. Therefore, it is considered that the consistency of the mode shapes in the continuous waveguide and the DBR becomes low and large connecting loss occurs at the interface between both. On the other hand, since the refractive index determined by the wave number and the frequency of shorter wavelength band is still larger than the refractive index of the clad, there is no scattering loss during the propagation in the shorter wavelength band. Therefore loss occurs not during propagation within the DBR but at the interface between the continuous waveguide and the DBR.

In addition, we also calculated including structure in consideration of absorption losses. The length of the DBR is 100 μm. The comparison with one-dimensional analyses is shown herein. In terms of the absorption loss, the absorption was set only to the core layer of the DBR region in the two-dimensional FDTD method. Absorption was set to the high refractive index area of the DBR region in the discrete method. In the coupled mode theory, uniform absorption loss was assigned since it is difficult to assign refractive indexes for each location in the longitudinal direction as the methods above.

The calculated reflectance is shown in Figure 7. In the coupled mode theory, the reflection is symmetrical with respect to the wavelength as a result the space distribution of absorption loss cannot be reflected. On the other hand, the reflectance becomes smaller in the long wavelength area of the reflection band in the discrete method. It is because in the long wavelength area of the reflection band, the standing wave locations in the high refractive index area where the absorption loss exists and then the absorption loss becomes large. Such effect is the same as the one using the DBR in which the active layer is etched, as introduced in the literature (reference 6). On the other hand, the reflection spectrum calculated with the two-dimensional FDTD method has a smaller reflectance in the shorter wavelength area. It seems that such reflection spectrum exists because, even though the absorption loss is larger in the longer wavelength area, the influence of the scattering loss in the shorter wavelength area of the reflection band as previously mentioned is prominent. This is a characteristic of this configuration which has no waveguide core in the low refractive index area, and is the result which cannot be obtained with the one-dimensional calculation. The reflectance is low overall, compared to the one from the calculation with the one-dimensional methods. Modeling considered the loss at the DBR interface is required for a design of the laser.

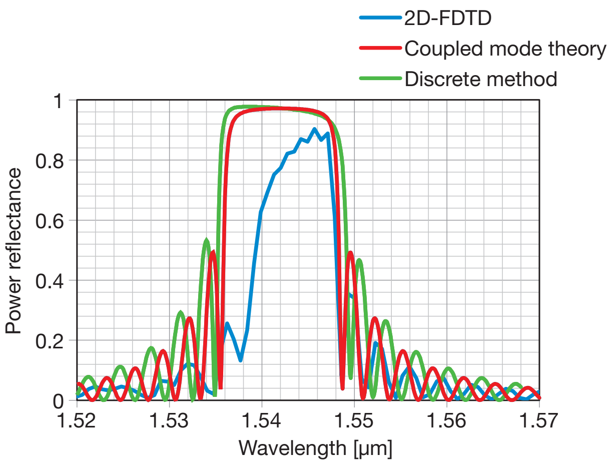

Figure 7 Comparison of the reflectance with the absorption loss calculated by various methods.

To examine the reflection spectrum of the DBR actually fabricated, we conducted an experiment. With the same manufacturing method as the DR laser, we made a sample in which the DBR region is the same as in the DR laser and in which the DFB region is just an emitting region without diffracting grating. When the current is injected to this sample, , the Amplified Spontaneous Emission (ASE) which is propagating backward as reflected at the DBR are seen in addition to the normal ASE light which is propagating forward from the emitting region. Therefore, the emitting spectrum shape which is corresponding to the reflection spectrum can be seen.

The measured spectrum is shown in Figure 8. The hump at the center of the graph is corresponding to the DBR reflection band. The shape of this spectrum is not symmetrical with respect to the wavelength and is gently weak in the shorter wavelength area. This agrees well with the reflection spectrum predicted by the calculations.

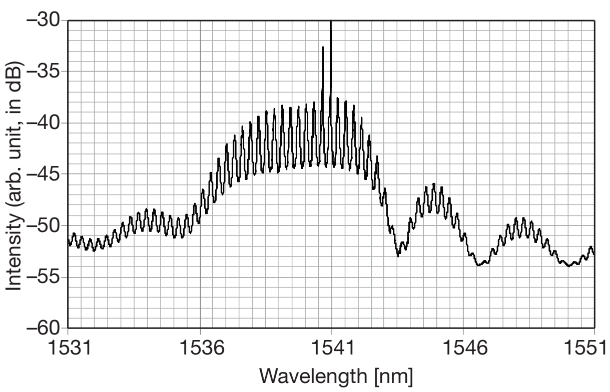

Figure 8 ASE spectrum of specimen with the DBR reflection.

2.4 Prediction of Linewidth Characteristic

The theoretical formula by Henry is well known as spectral linewidth of semiconductor laser [8), 10), 11)]. According to that, the linewidth can be expressed as

$$\Delta\nu = \frac{R_{sp}}{4\pi\hat{S}}(1+\alpha^2) = \frac{\upsilon_g^2 n_{sp}(\alpha_m+\alpha_i)^2}{4\pi\cdot(I-I_{th})}(1+\alpha^2)$$

where $\hat{S}$ is number of photons in a oscillator and R_{sp} is the amount of spontaneous emission coupled with the oscillator. If threshold gain ($\alpha_m+\alpha_i$) is decreased, the linewidth becomes small due to two effects: the number of photons in the oscillator increases (influence of noise relatively becomes small) and also the spontaneous emission which will be noise becomes small. The coefficient of (1+ α^2) is specific to semiconductor lasers, where “1” represents an effect that spontaneous emission directly disturbs the phase and “α^2” represents the effect that intensity change due to the spontaneous emission light causes the refractive index change and then frequency of the oscillator changes.

Although there is no large change in the concepts of a DFB laser or a DR laser, it is necessary to consider the space distributions of light. In the literature (reference 12), the rate equation of light is obtained by adopting Langevin power of spontaneous emission to coupled wave theory of a DFB, and then the linewidth of the (solitary) laser obtained as the result is

$$\Delta\nu = \frac{R_{sp}K_z}{4\pi S_{av}V_{act}}(1+\alpha_{eff}^{\ 2})$$

Here,

$$R_{sp} = n_{sp}\Gamma g \upsilon_g$$

is the spontaneous emission rate (number of spontaneous emission per hour) which is the gain per hour multiplied by inversion factor n_{sp},

$$K_z = \left[\frac{\int_0^L(|R_0^+|^2+|R_0^-|^2)dz}{4\left|\int_0^L R_0^+R_0^- dz\right|}\right]^2$$

is the longitudinal Petermann factor (R_0^+ and R_0^- are each amplitudes of forward wave and backward wave in the DFB at steady state with no influence of spontaneous emission),

$$S_{av}V_{act} = \frac{1}{h\nu\upsilon_g}\int_0^L(|R_0^+|^2+|R_0^-|^2)dz$$

is the number of photons in an oscillator,

$$\alpha_{eff} = \frac{\alpha\chi'+\chi''}{\chi'-\alpha\chi''}$$

is the effective linewidth enhancement factor. χ' and χ'' are each real part and imaginary part of

$\chi = \int_0^L\left(\frac{S_0(z)}{S_{av}}\right)\Gamma_z(z)dz$, and if χ'' is 0, α_{eff} becomes equal to the usual linewidth enhancement factor α.

On the other hand, our wavelength tunable light source chip has a Semiconductor Optical Amplifier (SOA) integrated, and the effect of the linewidth increment by ASE from a SOA should be considered. In the literature (reference 12), the linewidth of the DFB (DR) laser which has a SOA integrated becomes

$$\Delta\nu = \frac{\Gamma_l g_l v_g n_{sp,l} K_z}{4\pi S_{av} V_{act}}(1+\alpha_{eff}^2)\left[1+\frac{A-1}{\ln(A)}\frac{L_a}{L_d}\frac{n_{sp,a}\Gamma_a g_a}{n_{sp,l}\Gamma_l g_l}\alpha_r L_d\right]$$
$$= \Delta\nu_0\left[1+\frac{A-1}{\ln(A)}\frac{n_{sp,a}\Gamma_a g_a}{n_{sp,l}\Gamma_l g_l}\alpha_r L_d\right]$$

where a subscript of the DFB parameter is "l", a subscript of the SOA parameter is "a", A is the gain ratio, and the lengths of the DFB (DR) laser and the SOA are each L_d and L_a, and then, the linewidth of the single unit DFB, $\Delta\nu_0$, is expressed as increased as much as the ratio of the second term in the square brackets. Here, α_r is

$$\alpha_r = \frac{|R_0^+(L_d)|^2\,|t_2|^2}{\int_0^{L_d}(|R_0^+|^2+|R_0^-|^2)\,dz}$$

(where t_2 is amplitude coupling efficiency of the ASE at the end part), and is the value which will become equal to a value of $\alpha_m/2$ multiplied by $|t_2|^2$ if the configuration is symmetrical in froward/backward.

By the expressions above, it is possible to calculate the linewidth of the DFB (DR) laser which has the SOA integrated. The threshold gain and the electric field intensity distribution of the oscillation mode required for the calculation can be calculated by the coupled mode theory. At this time, modelization is performed to include scattering loss, described in the preceding section, at the DBR interface.

For the design of the DR laser, there is a flexibility with respect to the position of the phase shift or the coupling coefficient κ of the DFB region. The characteristic improvement by the DBR mirror can be used for improving either the forward output or decreasing the linewidth. Here, focusing on the latter, we chose the design which decreases the mirror loss α_m and makes the linewidth smaller. The calculated linewidth in comparison with the conventional DFB laser is shown in Figure 9. It is expected that the linewidth can be reduced by half compared to the DFB laser, by introducing the DR laser.

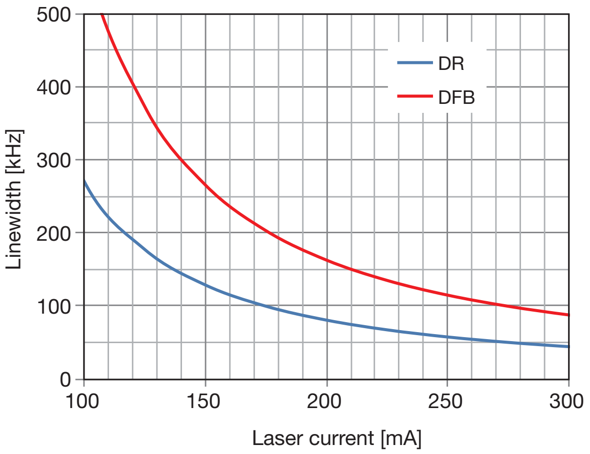

Figure 9 Calculated spectral linewidth.

3. WIDELY WAVELENGTH TUNABLE LIGHT SOURCE WITH DR LASERS INTEGRATED

3.1 Configuration of the Chip Fabricated

We fabricated a wavelength tunable light source by integrating a DR laser which is explained above. The picture of the fabricated chip is shown in Figure 10.

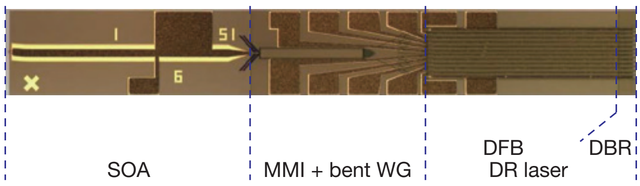

Figure 10 Fabricated tunable light source chip.

The configuration of the wavelength tunable light source chip is similar to the one that we have been manufacturing and is made of a 12-laser array which have different oscillation wavelength each, bent waveguides which guide the light from the array, an MMI coupler which combines light, and an SOA which amplifies the light. The wavelength is adjusted coarsely by selecting any of the 12 lasers and the temperature of the whole chip is changed by a Thermo Electric Controller (TEC) so that the refractive index of the laser is changed and to fine-tune the wavelength.

We used a DR laser for each laser of the laser array. There is a DBR in the backward region of the laser and the configuration is that no contact electrode to the semiconductor exists and the current is not injected in that region. Aside from that point, there is no change and the output difference compared to the conventional wavelength tunable light source chip is slight.

For a signal light source for long-distance communication, there is a demand for two wavelength regions such as C-band in the 1.55 μm band and L-band of longer wavelength. We fabricated chips corresponding to each wavelength band. 12 lasers' spectrum of each chip for the C-band and the L-band are shown in Figure 11 and Figure 12. The spectrum is measured by an optical spectrum analyzer with wavelength resolution of 0.1nm. Good single mode oscillation is obtained at all lasers.

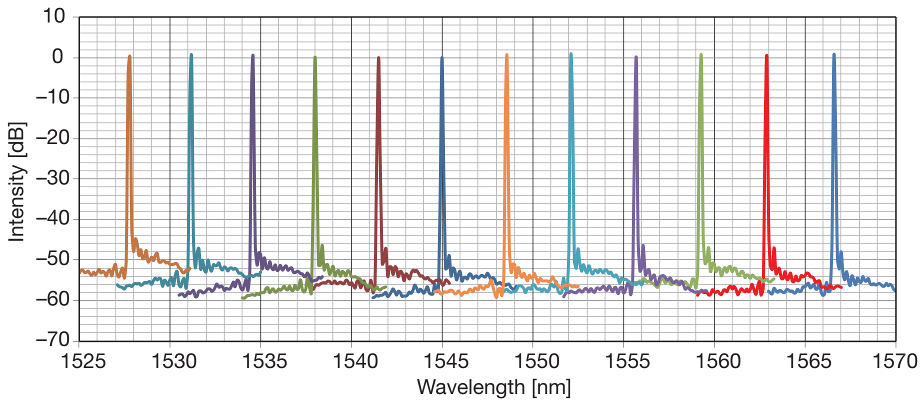

Figure 11 Output spectra of chip for the C-band.

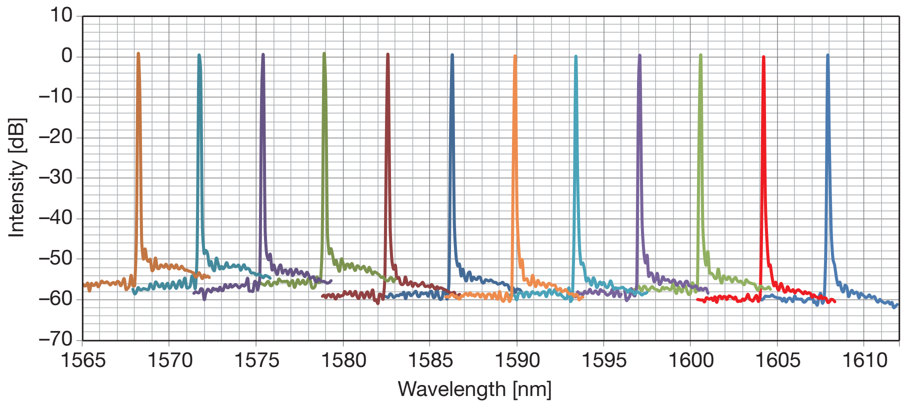

Figure 12 Output spectra of chip for the L-band.

3.2 Characteristic of Micro ITLA

We fabricated micro ITLAs with the configuration in Figure 1 by using fabricated chips.

The characteristic of the micro ITLA for the C-band is shown in Figure 13. The drive condition was set as output power became 17 dBm for this micro ITLA. Results for plural conditions are plotted since the temperature condition is changed for each of the 12 lasers on the chips in the operation.

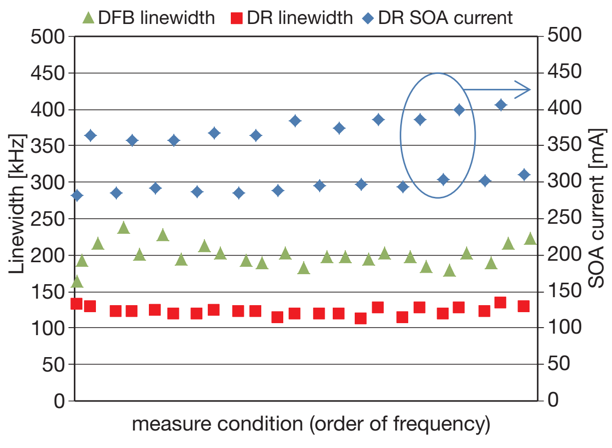

Figure 13 Characteristics of the micro ITLA (17 dBm optical output) for the C-band.

For linewidths, not only the result for the wavelength tunable light source chip which uses a DR laser but also the result for a chip which uses a DFB laser fabricated on the same wafer as a comparison are shown. The chip using the DR laser has significantly low linewidth of 110 – 140 kHz whereas the chip using the DFB laser has linewidth of 160 – 240 kHz. The range of the improvement is close to the predicted value by calculation.

High output power of 17 dBm was obtained with lower SOA currents up to 400 mA approx. Power consumption of End of Life (EOL; the value at the deterioration point of the fault determination value) was 4.2 W.

The characteristic of the micro ITLA for the L-band is shown in Figure 14. The drive condition was set as output power became 15.5 dBm for this micro ITLA.

Generally, it is difficult to achieve good characteristic with the L-band which has longer wavelength than that of the C-band. However, the chip using the DR laser can achieve linewidth less than 150 kHz at all tunable ranges of the wavelength.

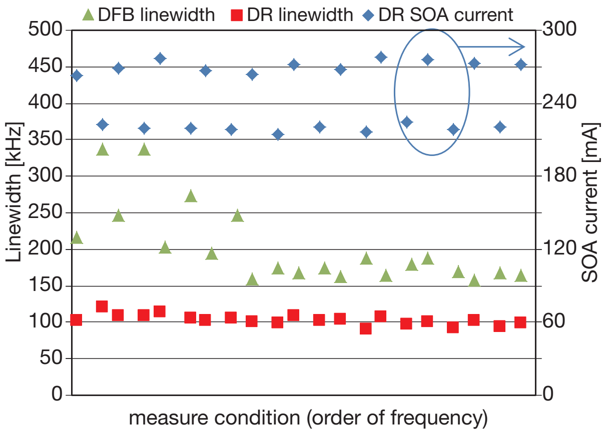

Figure 14 Characteristics of the micro ITLA (15.5 dBm optical output) for the L-band.

3.3 Reliability of Wavelength Tunable Light Source Chip

The reliability of the wavelength tunable light source chip fabricated was evaluated by high temperature aging test. 15 samples were aged at the temperature which is an accelerating condition simulating six times of real using condition. We drove the laser by constant current, drove the SOA with the constant output power condition and examined the change rate of the SOA drive current.

The result is shown in Figure 15. All chips showed a tendency of a slight and a gradual deterioration. Although the used DR laser includes an etched core in the DBR region whose material is the same as the one of the active layer, no abnormal variation of the driving current which suggests deterioration was observed and good reliability may be guaranteed. The FIT number after 20 years for a failure decision value of the driving current variation ratio was less than 50 FIT.

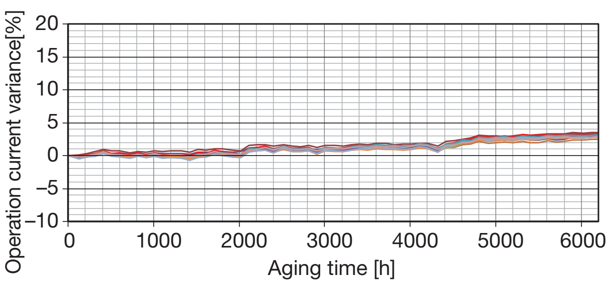

Figure 15 Aging result of tunable light source chip.

4. CONCLUSION

As a narrow spectral linewidth light source for a digital coherent communication, we developed a DR laser using an etched core type DBR and applied it to a wavelength tunable light source. Assembling the fabricated chip into the micro ITLA, we achieved the linewidth of less than 150 kHz at the output power of 17dBm for the C-band and 15.5dBm for the L-band. This narrow linewidth is useful for further multilevel of optical communication.

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