Mode Hopping Control and Lasing Wavelength Stabilization of Fiber Grating Lasers

*by Naoki Hashizume * and Hideyuki Nasu *2*

ABSTRACT Fiber grating lasers have been theoretically investigated. Stabilizing the conditions of the lasing wavelength of fiber grating lasers against temperature change is discussed on the basis of mode-hopping control. It is shown that, to reduce irregular and large-jump mode hopping, which originate in the longitudinal modes of the semiconductor optical amplifier chip, the front facet reflectivity of the chip should be less than 0.05 %. Two approaches to controlling mode hopping are proposed: extending the temperature period and reducing the wavelength change of hopping.

1. INTRODUCTION

In wavelength division multiplexing (WDM) systems, a coherent light source with a more accurate and more stable lasing wavelength is indispensable. In this context, distributed feedback (DFB) semiconductor laser diodes are widely used in systems as such single-mode laser light sources. At present, however, tuned DFB lasers are expensive because of a bad yield rate. Since the emission wavelength of a DFB laser depends heavily on temperature and injection current, it is difficult to sort out DFB laser modules which are tuned at predetermined wavelengths.

Recently, fiber grating lasers [1)~4)] (FGL) have been drawing attention as alternative light sources to DFB lasers in WDM systems. The structure of a FGL is illustrated in Figure 1; it consists of a semiconductor optical amplifier (SOA) with an anti-reflection (AR) coating formed on the front facet and a high-reflection (HR) coating on the back facet, and a fiber Bragg grating (FBG) acting as an external laser mirror. This type of semiconductor laser belongs to distributed Bragg reflector(DBR) lasers. The lasing wavelength of FGL is determined by the Bragg diffraction wavelength of FBG with high accuracy. Since FGL of a desired emission wavelength could easily be realized using FBG of an appropriate Bragg wavelength, FGL is much easier to manufacture at lower cost than conventional DFB lasers. Moreover, FGL lasing wavelength has less temperature dependence, because of the lower temperature sensitivity of FBG. On the other hand, since FGL is an external cavity laser in principle, it often exhibits mode hopping so that the lasing wavelength becomes unstable.

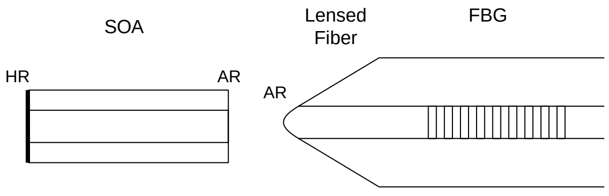

Figure 1 Schematic of a fiber grating laser

Regarding mode hopping of FGL, the reflectivity of the AR-coated front facet of SOA is one of the most important parameters. It is reported that the front facet reflectivity should be reduced to less than 0.01 % to eliminate kinks in power/current (LI) characteristics originating in mode hopping[5)]. In this paper FGL mode hopping is theoretically investigated to clarify how the residual reflection of the AR-coated front facet affects mode hopping and to obtain optimum conditions for a stable lasing wavelength. Theoretical analyses of FGL have been reported by several authors, but few attempts have been made to discuss the influence of front facet reflectivity in view of stabilizing the lasing wavelength.

2. MODE HOPPING

First, a brief review of mode hopping is presented. A typical graph of mode hopping is shown in Figure 2. Both resonant wavelength and peak gain wavelength usually depend on temperature. If they differ, the emission wavelength may suddenly jump to the neighboring mode: this is mode hopping.

Mode hopping is characterized by the following four variables, which are shown in Figure 2: The first is wavelength difference $\Delta\lambda$ due to mode hopping, which corre-

---

* Basic Technology Research Center, Yokohama R&D Laboratories

*2 WA Team, Yokohama R&D Laboratories

sponds to wavelength separation between two neighboring longitudinal modes of FGL. This is expressed as

$$\Delta\lambda = \lambda^2 / 2 L_{\mathrm{total}} ,$$

where λ is the lasing wavelength and L_{total} is the total optical pathlength of FGL cavity. The second is slope of lasing wavelength η, which corresponds to the temperature dependence of longitudinal modes of the laser cavity. This is expressed in terms of thermal expansion coefficient α as

$$\eta = \lambda\alpha.$$

The third is an evened-out slope of lasing wavelength η_{av}, which corresponds to the temperature dependence of a peak gain wavelength. In FGL cases, this also corresponds to the temperature dependence of the Bragg wavelength of FBG, as

$$\eta_{\mathrm{av}} = \lambda\alpha_{\mathrm{g}} ,$$

where $\lambda\alpha_{\mathrm{g}}$ is a thermal expansion coefficient of FBG. The fourth is the period of mode hopping ΔT, which is expressed as

$$\Delta T = \Delta\lambda \;/\; | \; \eta - \eta_{\mathrm{av}} \; |$$

for a simplified model.

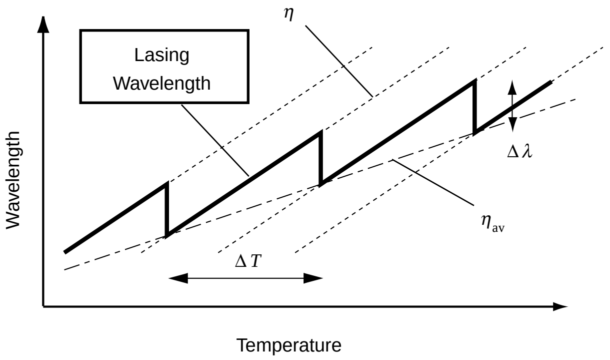

Figure 2 Typical graph of mode hopping

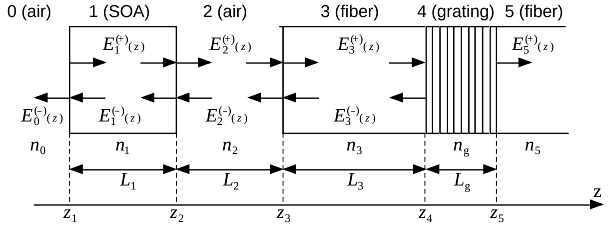

Figure 3 Simulation model of FGL

3. SIMULATION MODEL

We have analyzed a single-mode FGL oscillating at 1.5 μm as shown in Figure 3. The cavity length of SOA is 600 μm; the gap between the front facet of SOA and the facing facet of FBG is 10 μm; the distance between the FBG facet and the grating portion is 0.1 mm; the Bragg wavelength of FBG is 1545 nm; the maximum reflectivity of FBG is 20 %; the full width half maximum (FWHM) of the FBG reflectivity spectrum is 0.1 nm; the reflectivity of the AR-coated FBG facet is 0.01 %; the coupling rate of emitted laser light to a fiber is estimated to be 50 %. The rear facet of SOA reflects 90 % of light, and the front facet reflectivity varies from 0.01 % to 5 % in the calculation. All reflections at the boundaries are taken into account in the analysis using a transfer-matrix technique.

4. EFFECTS OF REFLECTIONS AT THE SOA FRONT FACET

Figure 4 shows four graphs of the lasing wavelength, where the reflectivities of the AR-coated front facet are 0.01 %, 0.1 %, 1 %, 2 %, respectively. Temperature variations are limited from 0°C to 50°C. One can see that the lasing wavelength exhibits the typical behavior of mode hopping if the front-facet reflectivity is 0.01 %. The higher

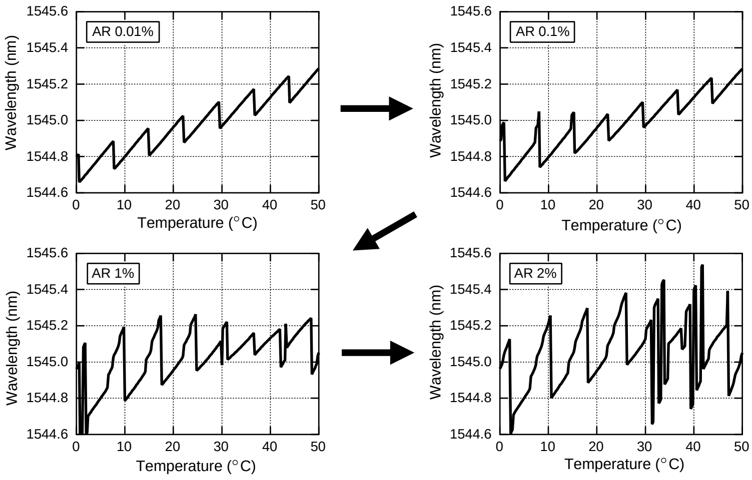

Figure 4 Lasing wavelength vs. temperature for several reflectivities of the SOA front facet

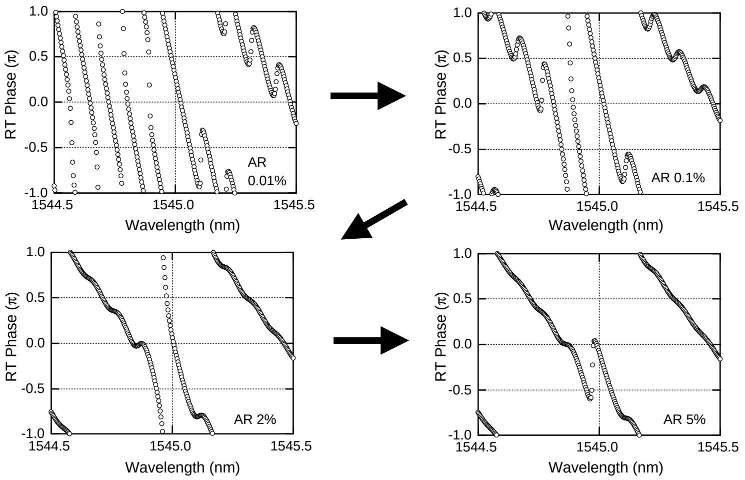

Figure 5 Round-trip phase of FGL for several reflectivities of the SOA front facet

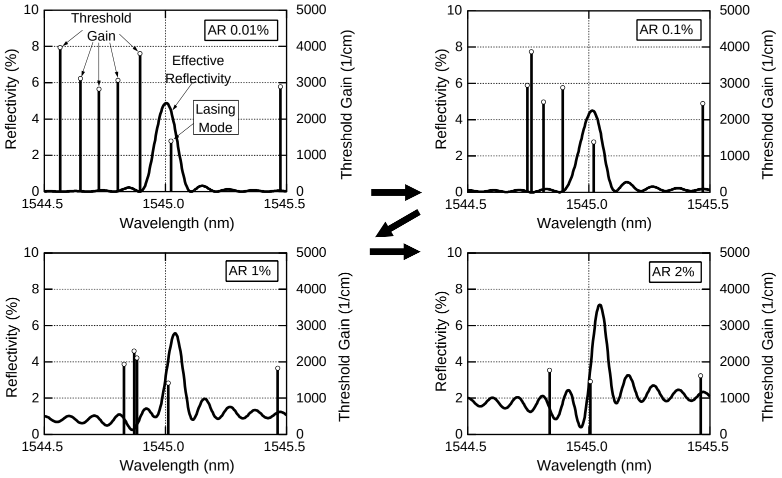

Figure 6 Effective reflectivity and threshold gain of FGL for several reflectivities of the SOA front facet

the reflectivity is, the more irregular the periodicity of mode hopping becomes and the larger the wavelength hops. It is noted that a reflectivity of 0.05 % would collapse periodicity in this system.

Next, we discuss the influence of the reflectivity of the AR-coated front facet to mode hopping. Figure 5 shows graphs of the round-trip phase where the front facet reflectivities are the same as in Figure 4. The points where the phase equals zero indicate the longitudinal modes of FGL. If the front facet reflectivity is 0.01 %, the round-trip phase crosses the horizontal axis frequently at the period of the longitudinal mode separation, whereas higher reflectivities make the phase reciprocating relax and reveal a longer period of oscillation. The new period corresponds to the longitudinal mode separation of the SOA-chip cavity alone. The higher the front facet reflectivity is, the more dominant the longitudinal modes of SOA becomes.

Figure 6 shows graphs of the effective reflectivity of the external mirror, the longitudinal modes and corresponding threshold gains of FGL. Laser oscillation occurs at the mode with minimum threshold gain. If the front facet reflectivity is 0.01 %, the threshold gain of the lasing mode is more twice as large as that of other modes. As reflectivity increases, both the number of longitudinal modes and the gain difference decrease. If the reflectivity reaches 2 %, three longitudinal modes exist which have almost the same threshold gains. In such a situation, since the minimum-gain mode transfers easily, the lasing mode would hop frequently and hops would be large.

Here let us briefly summarize this section. If the residual reflectivity of the AR-coated front facet increases, longitudinal modes originating in the SOA-chip cavity alone would have a large influence on FGL operation. The wavelength change would grow greater because of the large separation of wavelength between the SOA-chip-oriented modes, and mode hopping would occur frequently because there is little difference in threshold gain between the modes. These make the lasing wavelength unstable. From numerical analyses, it is concluded that the front facet reflectivity should be reduced to less than 0.05 % to remove the influence of the SOA-chip modes, which may account for the fact that the reflectivity has been reduced to less than 0.01 % to avoid kinks in LI characteristics 5).

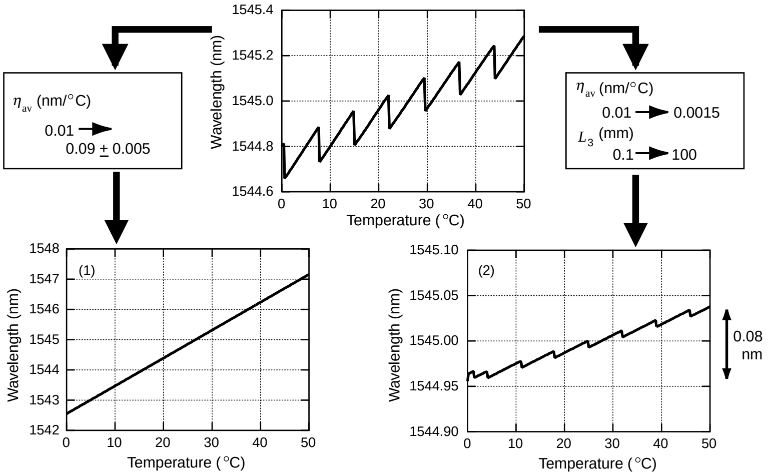

Figure 7 Two approaches to FGL lasing wavelength stabilization

5. CONTROL OF MODE HOPPING

Using the method described above to weaken the SOA-chip modes, irregular mode hopping would be removed and the lasing wavelength would present the typical periodic characteristics shown in Figure 2. Supposing the SOA-oriented longitudinal modes are removed, we should propose two approaches to controlling mode hopping, as follows:

1) Make the period of the mode hopping so long that the mode never hops within the applied temperature range. That is, decrease frequency of mode hopping; using appropriate packaging techniques, we should control the thermal expansion of FBG so that the slope of the FGL longitudinal mode matches that of the Bragg wavelength.
2) Reduce the evened-out slope η_{av} and the wavelength separation $\Delta\lambda$ to limit the net wavelength range to a predetermined value within the applied temperature range. That is, decrease degree of mode hopping using an athermal FBG, while extending the total cavity length of FGL simultaneously, we should shorten the wavelength variation.

In Figure 7 we demonstrate the above approaches. Temperature range is also limited from 0°C to 50°C. Adopting the first approach, one should tune the thermal expansion coefficient of FBG precisely within 0.09±0.005 nm/°C. Adopting the second, one should reduce the coefficient to less than 0.0015 nm/°C and, at the same time, extend the distance between the FBG facet and the grating region to more than 100 mm, thus attaining, for example, 0.1 nm of permissible wavelength deviation. Since the athermal FBG is much easier to get than the FBG with precisely controlled thermal expansion, the latter approach is more attainable in general.

6. CONCLUSION

In conclusion, we investigated mode hopping in fiber grating lasers theoretically and discussed stabilization of emission wavelength on the basis of mode-hopping control. Studying the influences of residual reflection of the AR-coated front facet of semiconductor optical amplifier on mode hopping, we found that the front reflectivity should be less than 0.05 % to remove irregular and large mode hops originating in SOA-chip-oriented longitudinal modes, which accounts for the previous experimental work. Besides, we propose two approaches to control mode hopping: making the period of mode hopping so large that no hopping occurs within the applied temperature range, and decreasing the degree of hopping to reduce wavelength deviation within the range.

REFERENCES

1) J-L. Archambault and S.G. Grubb: J. Lightwave Tech. 15 (1997) 1378.
2) T. Kato, T. Takagi, A. Hamakawa, K. Iwai and G. Sasaki: IEICE Trans. Electron. E82-C (1999) 357.
3) H. Nasu and H. Omura: Laser Kenkyu 27 (1999) 51.
4) F.N. Timofeev, P. Bayvel, V. Mikhailov, O.A. Lavrova, R. Wyatt, R. Kashyap, M. Robertson and J.E. Midwinter: Electron. Lett. 33 (1997) 1406.
5) R.J. Campbell, J.R. Armitage, G. Sherlock, D.L. Williams, R. Payne, M. Robertson and R. Wyatt: Electron. Lett. 32 (1996) 119.

Manuscript received on November 17, 2000.