Optical Directional Coupler for Narrow Spectral Linewidth Light

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In switching characteristics of optical directional coupler, an etalon effect is observed for the first time. We have studied the relation between this effect and laser spectra using three types of light sources. It is found that the etalon effect is strongly depend on the coherence properties of the light sources. In order to eliminate such a harmful problem, the waveguide facet reflectivities are reduced by chemical etching. As a result, remarkable improvement in switching characteristics is obtained and this device is promising for the application using highly coherent light.

§1. INTRODUCTION

Recently, considerable efforts have been paid for the developments of optical waveguide devices such as optical modulators and switches. 1-8) We have developed an optical directional coupler switch using InGaAsP/InP materials in order to realize monolithic opto-electronic integrated circuits.8) In switching characteristics, however, it is observed that total output power varies undesirably with bias voltage even at constant input optical power. We have analyzed this phenomenon based on Fabry-Perot Interference model and found that the variation is caused by the change of the optical path length in the waveguide with applied bias voltage. In this decade, there are many reports on passive waveguide devices, however, there is no report discussing about etalon effect in semiconductor passive waveguide with cleaved facets. This intereference effect will be a crucial problem when a single frequency light source with very narrow spectral linewidth is combined with the low loss waveguide in OEIC. We have investigated the switching properties of optical directional coupler and guiding characteristics of single waveguide. And it has been clarified for the first time, the relation of guiding characteristics input light coherence to properties in optical waveguide with cleaved

facets. Finally we have developed a novel directional coupler switch, which is applicable to the optical communication system using coherent light sources.

§2. ETALON EFFECTS IN OPTICAL DIRECTIONAL COUPLER

The optical directional coupler consists of a pair of closely spaced single mode strip-loaded waveguides with p-n junction as shown in Fig.1. Input light power was focused on a facet to excite TE mode and confined in the waveguide layer beneath the InP load layer. The optical switching is achieved through electro-optic effect by reverse biasing the p-n junction of one of the waveguides. An n⁻-InGaAsP(λ g=1.0µm, N_D=~2x10¹⁶ cm⁻³, d=~1.0µm) waveguide layer, n⁻-InP(N_p=~2X10¹⁶ cm⁻³, d=~0.1µm) buffer layer, p⁺-



Fig. 1. Structure of optical directional coupler,



Fig. 2. Switching characteristics in optical directional coupler with etalon effect.

 $InP(N_p = \sqrt{7} \times 10^{17} cm^{-3}, d = \sqrt{1} \mu m)$ clad layer and p^+ -InGaAsP($\lambda g=1.1\mu m$, $N_A = -2x10^{18} cm^{-3}$, d=~0.1um) contact layer were grown on $n^+-InP(N_n=\sim1x10^{18}$ cm⁻³) substrate by LPE method. Fig. 2 shows one of the switching characteristics of this device using He-Ne laser as a light source. In this case, the switch is 2 mm long(coupling length≃ 2.7mm), the guides are 2.7µm wide with a 3.3µm From the figure, optical swiching is spacing. performed principally, however, output power from each waveguide does not varies monotonously and the total power varies with bias voltage We have considered these output undesirably. power variations are derived from the etalon effect due to high reflectivity of the cleaved In order to investigate this effect facets. we measured an applied voltage precisely, dependence of output power using single waveguide, which has the same layered structure as optical directional coupler. SEM image of the single waveguide is shown in Fig. 3.

Three types of light sources are employed in this experiment, and their spectral properties are described in Table 1. Experimental setup for this measurement is shown in Fig. 4. Spectral characteristics of lasers are monitored by using monochrometer with resolution of 0.5Å or Fabry-Perot Interferometer(FPI). Optical output power is detected by Ge pin-photodiode. Optical isolator with isolation ratio of ~30dB is set between light source and waveguide, and it is removable to study the etalon effect with and without optical feedback from the waveguide facet to the laser.



Fig. 3. SEM photograph of single waveguide.

Table 1. Spectral parameters of light sources.

	He-Ne laser	InGaAsP BH laser	InGaASP MEC laser
wavelength(µm)	~1.15	~1.30	~1.28 85/267(act./pass.)
longitudinal mode	multiple	multiple	single
mode spacing(GHz)	~0.2 n ~0.6	~140 ~300	~0.015
(GHz)	(envelope)	(envelope)	



Fig. 4. Experimental setup for observing characteristics of waveguide devices.

§3. EXPERIMENTAL RESULTS IN SINGLE WAVEGUIDE

To analyze the output power variation caused by etalon effect quantitatively, a parameter of visibility is introduced;

where P_{max} and P_{min} are the maximum and minimum output power with bias voltage. Tested sample length is 2mm, accordingly the free spectral range(FSR=c/2nL, c;light velocity in free space, n;refractive index of the waveguide, L;waveguide length) is ~22 GHz and finesse is ~2.5. In the following, light source dependence of the output power variations caused by etalon effect are reported.

a) He-Ne laser

Measured output power variations with applied bias voltage are shown in Fig. 5 for both cases

with and without isolator and they give the same visibility of ~0.51. Corresponding optical spectra observed by FPI with FSR of 3GHz are also shown in Fig. $5(\lambda_0=1.15\mu\text{m})$. Although the difference of the optical spectral shape is appreciable, envelope spectral width are almost the same as ~600MHz for both cases. This is why same visibility is obtained. It is noted that the increase of noise component of the output power in case without isolator as shown in Fig. 5 is caused by optical feedback.

b) BH laser

Fig. 6 shows output power variations with applied bias voltage in InGaAsP BH laser(I=40mA; $I_{th}=20$ mA, $\lambda_{o}=1.30$ µm). Obtained values of the visibility in case with and without isolator are about 0.1 and 0.03, respectively. As clearly seen, this laser exhibits multimode oscillation and spectral linewidth is much broadened, especially in case without isolator. Therefore the reduction of output power variations are considered to be reasonable. Optical feedback effect on the noise component is also observed in the case without isolator.

c) Monolithic External Cavity Laser(MEC laser)⁹⁾ InGaAsP laser, in which transparent waveguide is monolithically integrated as an external exhibits single frequency oscillation cavity, with extremely narrow spectral linewidth and the obtained narrowest value is 900kHz. The spectrum of the laser employed in this experiment are shown in Fig. 7(I=90mA; I $_{\rm th}$ =60mA, λ =1.28 μ m), which are monitered by using monochrometer and FPI with FSR of 10 GHz. The actual specral linewidth is confirmed to be ~15MHz by delayed self-heterodyne beat measurement because of the resolution limit of the FPI. In this case obtained visibility is ~ 0.41 , which is rather high compared with the case of BH laser. In case without isolator, which is not shown in the figure, the visibility did not decrease as the case of the BH laser. The detail output power variation properties still are under investigation.

In the following, we discuss about the experimental results. In He-Ne laser, even though it exhibits multimode oscillation, the envelope spectral width of ~ 600 MHz is rather narrow compared with the transmission band width of the waveguide etalon. Therefore, the observed visibility of 0.51 is considered to be almost the maximum value of the waveguide etalon. In BH



Fig. 5. Output power variations with bias voltage in case with and without isolator using He-Ne laser(=1.15µm), and their spectral shapes observed by FPI(FSR=3GHz). Fig. 6. Output power variations with bias voltage in case with and without isolator using BH laser, and their spectral shapes observed by monochrometer. Fig. 7. Output power variation with bias voltage in case with isolator using MEC laser, and its spectral shape observed by monochrometer and FPI(FSR=10 GHz) laser, the envelope spectral width spread over 300GHz, so the output power is the sum of each frequency components passing through the waveguide etalon with FSR of 23GHz. It is reasonable to give the low visibility. For MEC laser, because of the spectral width is very narrow as 15MHz, the obtained visibility of 0.41 is rather high compared with that in case of BH laser. And this value is considered to be the maximum for the combination of the MEC laser and the waveguide etalon. However, it is slightly small compared with that of the He-Ne laser case. This is due to slightly larger propagation loss in wavelength of 1.28µm since this waveguide is designed for the wavelength of 1.15µm. Estimated loss of this waveguide by obtained visibility are 0.4 and 1.5 cm-1 for wavelength of 1.15 and These values agree with 1.28µm, respectively. other exprimental results. The increase of the propagation loss is considered to be due to the increases of surface scattering with decreasing optical confinement and free carrier absorption. it is found that the As described above, completely different power variations are observed even though the same waveguide is used. This discrepancy is due to the difference of coherent properties of the light sources.

§4. IMPROVEMENT OF OPTICAL DIRECTIONAL COUPLER

To reduce these output power variations caused by the waveguide etalon effect, the reflectivities of the facets are reduced by chemical etching using H2S04-H202-H20 solution. This process is effective and simple compared with anti-reflection coating. By this method, the visibility is successfully decreased below 0.03. Then we adopted the etching process in fabrication of the optical directional coupler. As a result we have realized a drastically improved switching properties as shown in Fig. 8 compared with the case shown in Fig. 2. In this measurement. He-Ne laser is used as a light source. The performances of this switch are as follows, Switching Voltage:-14.8(V), Extinction Ratio:-18dB(through state), -16dB(cross state), Device Length: 2.4mm, Total Output Power Deviation:-20dB.



Fig. 8. Switching characteristics in improved optical directional coupler.

§5. CONCLUSIONS

We investigated etalon effects in the optical waveguide device with cleaved facets using three light sources. It is found that completely different output power variations caused by etalon effect are observed in the same waveguide. This harmful etalon effect was eliminated by slight etching the cleaved facet, and we realized a novel optical directional coupler which is applicable even to the narrow spectral linewidth light source.

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