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Extremely Narrow Spectral Linewidth Oscillation of Low Threshold Current Integrated-Passive-Cavity Laser

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A 1.3um wavelength InGaAsP/InP monolithic integrated-passive-cavity (IPC) laser, which has a long passive optical waveguide as an external cavity, has been fabricated. Improving mode coupling between the active and the passive cavity sections, the IPC laser with a 1.33mm long passive cavity has operated in low threshold current of 32mA and the extremely narrow spectral linewidth of 700kHz has been achieved.

§1. Introduction

Semiconductor lasers for coherent optical transmission systems and fiber sensors require a spectral linewidth of less than 1MHz. Since the linewidths for InGaAsP lasers range from several megaheltz to several hundred megaheltz, further reduction is necessary. Although very narrow linewidths have been obtained in external cavity lasers,[1)-3)] elimination of the thermal and mechanical instability is difficult due to hybrid configurations.

To realize a stable narrow linewidth light source, we developed an integrated-passive-cavity (IPC) laser for the first time and obtained 900kHz linewidth.[4),5)] Over the last few years, several semiconductor lasers with integrated external cavities have been reported.[6)-8)] Single frequency oscillation have been realized in such lasers, however, the linewidth is in the range of 1 or 2MHz. It is due to high optical loss of an external cavity or low mode coupling between the active and the external cavity sections.

This paper reports further linewidth narrowing of the IPC laser. Improving mode coupling between the active and the passive cavity sections, threshold current has been reduced to 32mA and 700kHz linewidth has been achieved at an output power of 5mW for a 1.33mm long passive cavity.

§2. Device Structure and Fabrication

The IPC laser structure is shown schematically in Fig.1. A long and transparent optical waveguide is formed adjacent to the active region with a self-aligned loaded guide structure. The active region has a conventional buried heterostructure. The light from the active cavity is coupled to the waveguide at etching interface and the

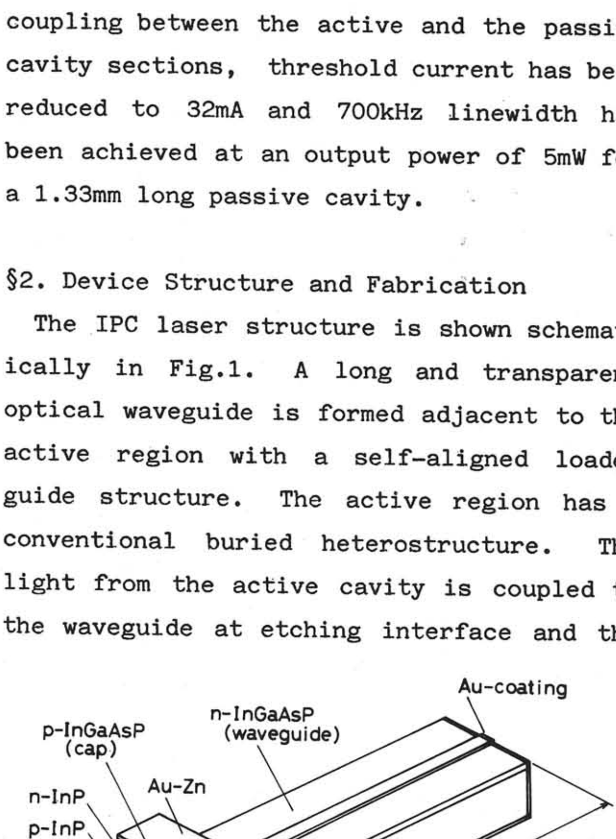

Fig.1. Schematic drawing of a IPC laser.

light is reflected back into the active cavity by the cleaved facet of the waveguide. This facet is coated with gold(Au) film to increase the optical feedback power.

The fabrication of the device involves the following steps. First, six layers were grown on (100) oriented n^+-InP substrate, which were an n-InP buffer layer, an n-InGaAsP waveguide layer (band-gap wavelength λ_g=1.05μm, 0.6μm thick), an n-InP separation layer (0.2μm thick), an undoped InGaAsP active layer (λ_g=1.3μm, 0.13μm thick), a p-InP clad layer, and a p-InGaAsP cap layer. Then stripe mesa etching and regrowth of p-InP and n-InP were done. In mesa etching, the wafer was etched down to the surface of the separation layer using a SiO_2 stripe mask. The stripe width of the active layer was ~ 2.5um.

After the second growth, the cap layer, the clad layer and the active layer of the passive cavity region were selectively etched off. As a result, the stripe-shaped separation layer, which was self-aligned to the active stripe, was left on the waveguide layer. The separation and waveguide layers formed a loaded waveguide. In this waveguide structure, the optical loss in the passive cavity is expected to be low because the light is confined transversely under the load. Then the Au-Zn contact was formed on the active cavity and the Au-Sn contact on the substrate side.

§3. Results and Discussions

The light output vs. current characteristics under pulse operation at room-temperature are shown in Fig.2, where (a) is the IPC laser before Au-coating, (b) after Au-coating and (c) a conventional laser. The length of the active and passive cavities in the IPC laser were 280um and 1.33mm, and the conventional laser had a 220um long cavity, which was the same geometry as the active cavity of the IPC laser. Threshold currents were (a) 49mA, (b) 32mA and (c) 33mA, respectively. Threshold current of the IPC laser was reduced to 2/3 with Au-coating and its value was much the same as the conventional laser. It is considered that the low threshold of the IPC laser is due to higher coupling efficiency between the active and the passive cavity sections caused by improvement of the etched interface structure.

The threshold current of an IPC laser is written in the form

$$I_{th} \propto \alpha_{in} + (1/\ell)\ln(1/r_2 r_e) \qquad (1)$$

with

$$r_e = (r_1 + r_0)/(1 + r_1 r_0) \qquad (2)$$

and

$$r_0 = \eta_c \exp(-\alpha_0 L) r_{op}. \qquad (3)$$

Here, r_{op}, r_1 and r_2 are amplitude reflectivities of the waveguide facet, the coupling point between the active and the passive cavity sections, and the cleaved facet of the active cavity, respectively. r_e

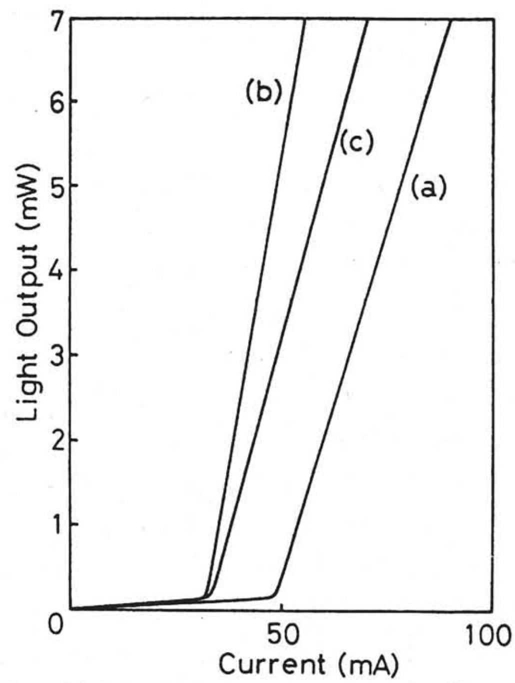

Fig.2. Light output vs. current characteristics of (a) the IPC laser before Au-coating, (b) after Au-coating, (c) the laser without passive cavity.

is the effective reflectivity including the passive cavity at the coupling point. ℓ and L are the length of the active and the passive cavity, respectively. α_{in} is the internal loss of the active cavity. α_0 is the propagation loss of the waveguide. η_c is the coupling efficiency between the active and the passive cavity sections.

η_c in the IPC laser is estimated to be about 70% from the relative reduction in threshold current due to Au-coating of the waveguide facet. Here we used α_{in}=40cm^{-1}, α_0=1cm^{-1}, which were obtained experimentally, r_{op}=0.3 before Au-coating, and r_{op}=1 after Au-coating in Eq.(1)-(3). η_c of 70% is large as compared with the value calculated from mode coupling theory. It may be necessary to consider the effect of the internal loss reduction due to the shift to longer wavelength of the lasing mode with Au-coating.[9] The detail for estimation of η_c in the IPC laser will be clarified in near future.

The longitudinal mode characteristics of the IPC laser with Au-coating, measured at 18 °C and cw operation for several driving currents, are shown in Fig.3. The IPC laser exhibited stable single frequency oscillation just above the threshold due to the mode selectivity of the coupled cavity.[10] Although by increasing the driving current, longitudinal submodes appeared, the single frequency oscillation was maintained in the range of about 30mA up to 60mA. The maximum ratio of main to submode exceeded 30dB.

The spectral linewidth of the IPC laser with Au-coating was measured by utilizing a delayed self-heterodyne technique. An acousto-optic modulator was used to give a 120MHz frequency shift, and a 5km long single mode fiber was used as the optical delayline. The resolution of this system was about 10kHz. Two optical isolators (more than 60dB isolation) and AR-coated lenses were used to eliminate the reflection from various optical components.

Fig.4 shows the linewidth and the ratio of main to submode dependence on the driving current. It seems that the linewidth is strongly affected by the submodes.[11] The linewidth was narrowed when the submodes were suppressed, while it was broadened when the submodes appeared. The minimum linewidth was about 700kHz at 5mW output power. Fig.5

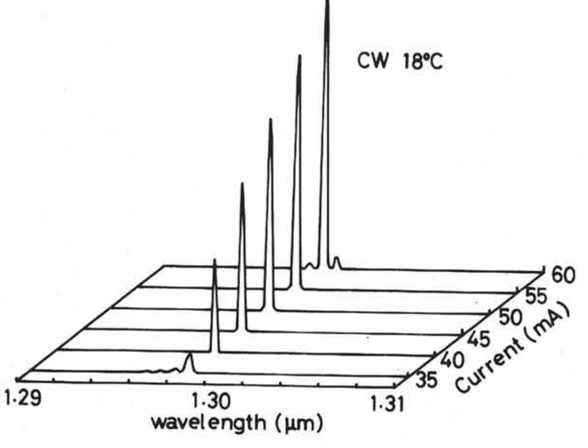

Fig.3. Longitudinal mode characteristics of the IPC laser with Au-coating for several driving currents.

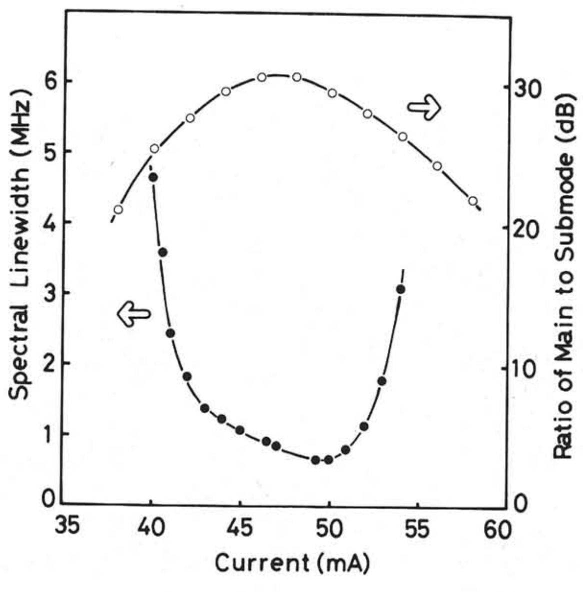

Fig.4. Spectral linewidth and ratio of main to submode vs. current characteristics of the IPC laser with Au-coating.

shows a measured beat spectrum of 700kHz linewidth. It is found to be close to Lorentzian lineshape.

The spectral linewidth of the external cavity semiconductor lasers is expressed as[12])

$$\Delta\nu = R/4\pi(S+S_1)+\alpha^2\beta^2 R/4\pi S. \qquad (4)$$

Here R is the spontaneous emission rate per laser mode, S and S_1 are the number of photons in the active and the external cavity, respectively, α is the linewidth enhancement factor and β is the ratio of the resonance frequency change of the laser with and without an external cavity.

The first term of Eq.(4) is the linewidth due to the phase change caused directly by each spontaneous emission event, and the second is one arising from the refractive index change.

For narrowing the linewidth, large external cavity length and strong optical feedback, that is the increase in η_c and r_{op} and the decrease in α_0, are effective. It is considered that the 700kHz linewidth of the IPC laser is due to the strong optical feedback with higher coupling efficiency between the active and the passive cavity sections.

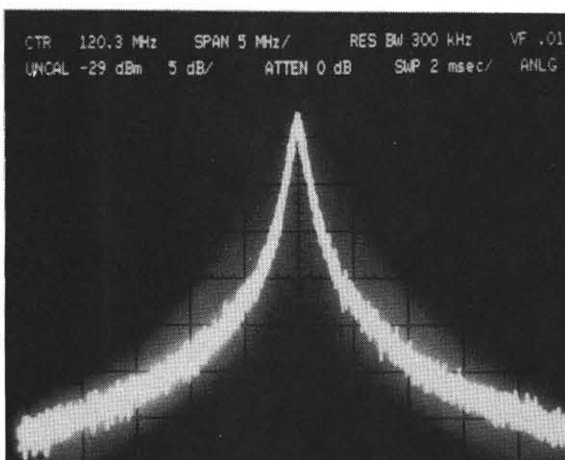

Fig.5. Example of measured beat spectrum of the IPC laser with Au-coating, Horizontal scale: 5MHz/div; vertical scale: 5dB/div.

§4. Summary

We have fabricated a 1.3μm wavelength InGaAsP/InP monolithic integrated-passive-cavity (IPC) laser which has a long passive optical waveguide as an external cavity. With improved mode coupling between the active and the passive cavity sections, the IPC laser with a 1.33mm long passive cavity has operated in low threshold current of 32mA and the extremely narrow linewidth of 700kHz has been achieved. Narrower linewidth could be realized for an IPC laser with a longer passive cavity.

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Reference

1) S. Saito, O. Nilsson, and Y. Yamamoto, IEEE J. Quantum Electron. QE-18 (1982) 961.
2) K. Kikuchi, and T. Okoshi, Electron. Lett. 18 (1982) 10.
3) R. Wyatt, and W. J. Devlin, Electron. Lett. 19 (1983) 110.
4) K. Matsuda, T. Fujita, J. Ohya, M. Ishino, H. Sato, H. Serizawa, and J. Shibata, Appl. Phys. Lett. 46 (1985) 1028.
5) T. Fujita, J. Ohya, K. Matsuda, M. Ishino, H. Sato, and H. Serizawa, Electron. Lett. 21 (1985) 374.
6) S. Murata, S. Yamazaki, I. Mito, and K. Kobayashi, Electron. Lett. 22 (1986) 1197.
7) T. P. Lee, S. G. Menocal, S. Sakano, V. Valster, and S. Tsuji, Electron. Lett. 23 (1987) 154.
8) N. K. Dutt, T. Cella, J. L. Zilko, A. B. Piccirilli, R. L. Brown, and S. G. Napholtz, Appl. Phys. Lett. 50 (1987) 644.
9) J. C. Goodwin, and B. K. Garside, IEEE J. Quantum Electron. QE-19 (1983) 1492.
10) H. Sato, T. Fujita, and J. Ohya, IEEE J. Quantum Electron. QE-21 (1985) 284.
11) H. Sato, and T. Fujita, Appl. Phys. Lett. 47 (1985) 562.
12) H. Sato, and J. Ohya, IEEE J. Quantum Electron. QE-22 (1986) 1060.