SURFACE-EMITTING GaInAsP/InP INJECTION LASER WITH SHORT CAVITY LENGTH

Indexing terms: Semiconductor devices and materials, Semiconductor lasers

We have succeeded in making a surface-emitting GaInAsP/InP injection laser with short cavity length (≅ 10 μm) which operates at 1·22 μm of wavelength with threshold current of 160 mA (33 kA/cm²) at 77 K. No side-emitting mode was observed as a result of preparing long absorbing regions and a small dot electrode (25 μm ϕ). One of the longitudinal modes, with a spacing of 170 Å, dominated above threshold and the far-field radiation angle was sharp (2Δθ = 10°).

Introduction: A surface-emitting (SE) injection laser was realised by Melngailis with InSb at 10 K,[1] and by the authors with GaInAsP at 77 K for three types of structures: planar structure,[2] buried heterostructure[3] and planar buried heterostructure.[3] Threshold currents were high (500 mA at lowest), and unwanted side emitting modes were often observed.

In this letter we describe the first surface-emitting GaInAsP/InP injection laser with short cavity length as shown in Fig. 1. For the purpose of reducing the threshold current and suppressing the side-emitting mode, we have introduced the following improvements:[4] (*a*) the utilisation of only double-heterostructure epitaxial layers by removing the lossy substrate, which was also effective for getting plain and parallel mirrors, (*b*) thick active layer for increasing the gain region, (*c*) gold-plated reflecting mirror for increasing reflectivity, (*d*) small *p*-side electrode for reducing the super-radiance of the side-emitting mode, and (*e*) long passive region for suppressing the oscillation of the side emitting mode.

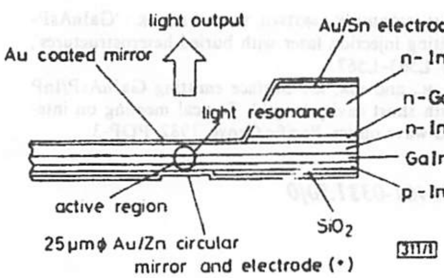

Fig. 1 *Schematic view of a surface-emitting GaInAsP/InP injection laser with short cavity length*

Fig. 2 *Cross-sectional SEM view of SE laser with short cavity length*

Fabrication: $Ga_xIn_{1-x}As_yP_{1-y}$ wafers were prepared by using the 2-phase solution LPE growth technique. Four layers, i.e. *n*-type GaInAsP (etch-stopping layer, Te-doped, 1·5 μm), *n*-type InP (Te-doped, 2·5 μm), undoped GaInAsP (active layer, 2·9 μm), and *p*-type InP (Zn-doped, 5·0 μm), were grown successively on the (100)-oriented *n*-type InP substrate. After the *n*-side surface was polished to 120 μm thick, the *n*-side electrode was formed by evaporating Au/Sn metal. Next, an

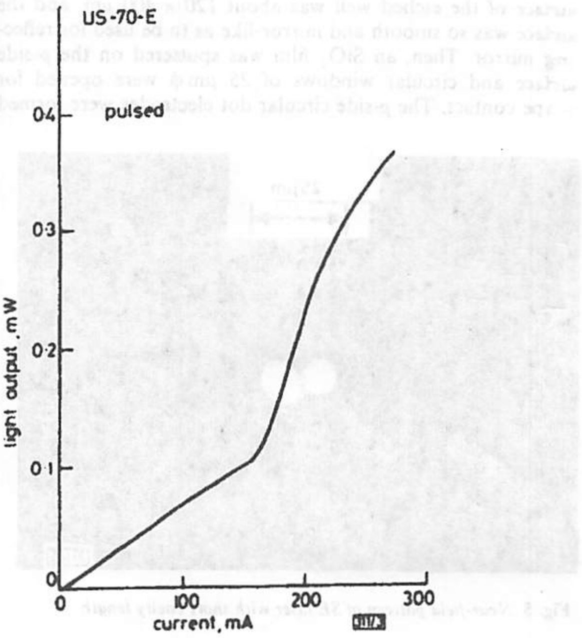

Fig. 3 *Light-output/current characteristic at 77 K*

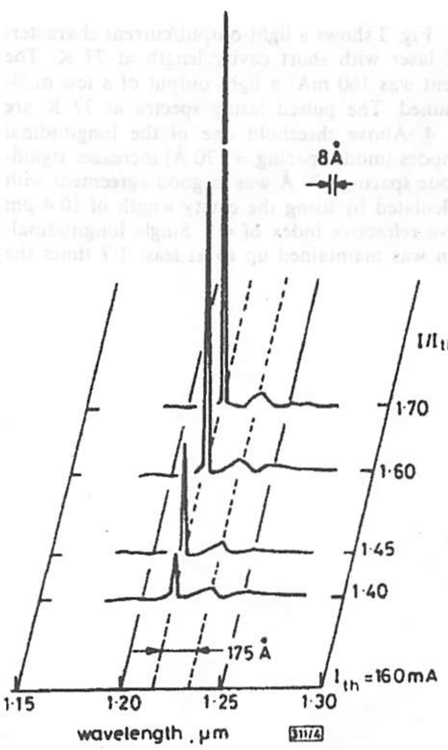

Fig. 4 *Emission spectra of SE laser with short cavity length*

SiO_2 film was sputtered and circular windows of 400 μm ϕ were opened to etch-off the substrate. The exposed Au/Sn was etched by the mixed solution of $HCl:CH_3COOH:H_2O$ (= 1:2:1) at 15°C for few minutes and then the substrate was etched by the mixed solution of $HCl:H_2O$ (= 4:1) at 20°C. It took about 20 min to reach the epitaxial *n*-type GaInAsP etch-stopping layer. Then, the GaInAsP etch-stopping layer was etched off for getting smoother first InP layer surface. The cavity length was 10·4 μm as indicated in Fig. 1; the cross-sectional view of a laser chip is shown in Fig. 2. The size of the

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surface of the etched well was about 120 × 400 μm, and the surface was so smooth and mirror-like as to be used for reflecting mirror. Then, an SiO_2 film was sputtered on the *p*-side surface and circular windows of 25 $\mu m \phi$ were opened for *p*-type contact. The *p*-side circular dot electrodes were formed by evaporating Au/Zn metal onto the InP epilayer. Finally, the etched surface was coated with gold film for increasing reflectivity.

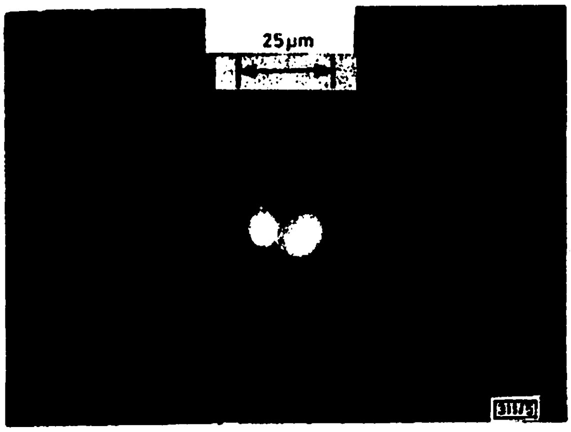

Fig. 5 *Near-field pattern of SE laser with short cavity length*

Characteristics: Fig. 3 shows a light-output/current characteristic of the SE laser with short cavity length at 77 K. The threshold current was 160 mA; a light output of a few milliwatts was obtained. The pulsed lasing spectra at 77 K are shown in Fig. 4. Above threshold one of the longitudinal Fabry-Perot modes (mode spacing = 170 Å) increases significantly. This mode spacing 170 Å was in good agreement with the number calculated by using the cavity length of 10·4 μm and the effective refractive index of 4·1. Single longitudinal-mode operation was maintained up to at least 1·7 times the threshold. Fig. 5 shows a near-field pattern of the lasing mode at 77 K. The distribution of optical intensity was not circular. This is considered to be caused by the nonuniformity of the *p*-side mirror reflectivity. The far-field radiation angle (FWHM) was as narrow as 10 degrees. However, it would become narrower by making the mirror reflectivity and cavity length uniform over 25 $\mu m \phi$. Further reduction of the threshold current and current density could be achieved by increasing the active layer thickness and mirror reflectivity.

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