Single Transverse Mode Operation of Over 10 μm Wide Ridge-Type Semiconductor Lasers with Transversal Diffraction Gratings

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***Abstract-* This paper reports on single transverse mode operation of a ridge-type semiconductor laser with transversal diffraction gratings for a mesa width over 10 μm when the number of periods is 160, the grating pitch is 428.7 nm, and the grating depth is 250 nm.**

I. INTRODUCTION

In long-haul optical fiber communication systems, erbium doped optical fiber amplifiers (EDFAs) have been utilized. As pumping sources of EDFAs, high power 980-nm semiconductor lasers, in which AlGaAs layers are used as cladding layers and guiding layers, have been utilized [1]. If AlGaAs layers are oxidized, electrical and optical characteristics of 980-nm semiconductor lasers are highly degraded. As a result, in order to avoid oxidization of AlGaAs layers during etching process, 980-nm semiconductor lasers have ridge structures for confining horizontal transverse modes.

In the ridge-type semiconductor lasers, when the mesa width is larger than 2 μm, not only the fundamental horizontal transverse mode but also higher-order horizontal transverse modes are confined to their optical waveguides. Therefore, with an increase in injected current, higher-order horizontal transverse modes lase, which causes kinks in their light-output versus current (*L-I*) curves [2]. Below the kink level — the light output where a kink appears in *L-I* curves — only the fundamental horizontal transverse mode oscillates. Above the kink level higher order horizontal transverse modes oscillate. The higher-order horizontal transverse modes have much lower light coupling efficiency between 980-nm semiconductor lasers and EDFs than the fundamental horizontal transverse mode, leading to low pumping efficiency for EDFAs.

In order to achieve high light coupling efficiency between 980-nm semiconductor lasers and EDFs, high kink level or kink-free operation is needed for 980-nm semiconductor lasers. To satisfy this requirement in 980-nm ridge-type semiconductor lasers, lossy metal layers [3], highly resistive regions in both sides of ridge stripe [4], incorporation of a graded V-shape layer [5], optical antiguiding layers [6], [7], separate confinement of carriers and horizontal transverse mode [8], horizontal coupling of horizontal transverse modes by a groove in the mesa [9], and transversal diffraction gratings [10] have been demonstrated.

In this paper, ridge-type semiconductor lasers with transversal diffraction gratings are simulated, and kink-free operation is obtained up to the injected current of 3 A for a wide mesa up to 11 μm.

II. OPERATING PRINCIPLE AND STRUCTURE

Figure 1 shows a schematic cross-sectional view of the facet of the 980-nm ridge-type semiconductor laser with transversal diffraction gratings. The transversal diffraction gratings generate the difference between the spatial distribution of the fundamental horizontal transverse mode and those of higher order horizontal transverse modes. As a result, only the fundamental horizontal transverse mode is confined in the gain region while the higher order horizontal transverse modes are located in the loss region. In Fig.1, W is the mesa width, S is the space between the mesa and the transversal diffraction gratings, Λ is the grating pitch, and d is the grating depth. The height of the mesa is 1.55 μm. The cavity length is 1200 μm. Power reflectivity of the front facet and that of the rear facet are 2 and 90%, respectively. Layer parameters are the same as those described in Refs. 6-10.

Lasing characteristics are simulated by using a device simulation software ATLAS (Silvaco) in which Poisson's equations and Helmholtz equation are solved with a finite element method.

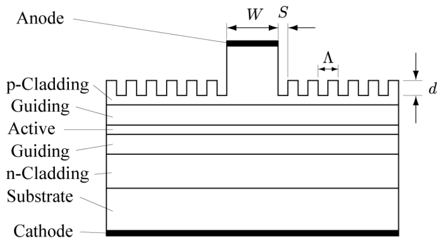

Fig. 1 Schematic cross-sectional view of the facet of the 980-nm ridge-type semiconductor laser with transversal diffraction gratings.

III. SIMULATED RESULTS AND DISCUSSIONS

Figure 2 shows injected current versus applied voltage (*I-V*) curves when the number of grating periods in one side *N*=160, *S*=426 nm, Λ=428.7 nm, and *d*=250 nm. The parameter is the mesa width *W*. With an increase in *W*, a differential electrical resistance decreases because the cross-section of the pass for the injected current increases.

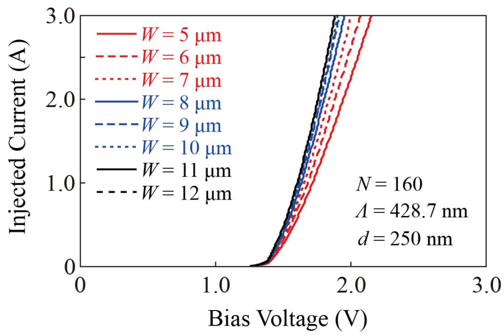

Fig.2 Injected current versus applied voltage when *N*=160, Λ=428.7 nm, and *d*=250 nm. The parameter is the mesa width *W*.

Figure 3 shows *L-I* curves when *N*=160, Λ=428.7 nm, and *d*=250 nm. The parameter is the mesa width *W*. When 5 μm ≤ *W* ≤ 11 μm, kinks do not exist in *L-I* curves; only the fundamental horizontal transverse mode oscillates up to the injected current of 3 A. When *W*= 12 μm, a kink appears in the *L-I* curve.

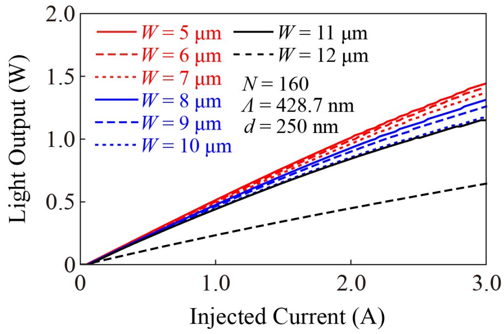

Fig.3 Light output versus injected current when *N*=160, Λ=428.7 nm, and *d*=250 nm. The parameter is the mesa width *W*.

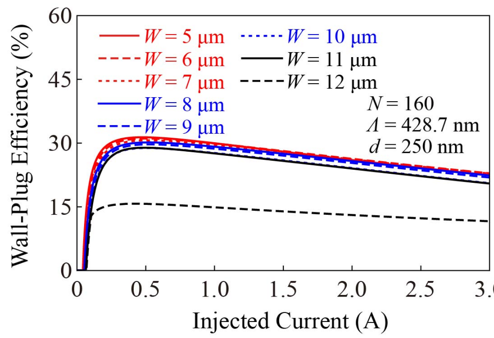

Fig.4 Wall-plug efficiency versus injected current when *N*=160, Λ=428.7 nm, and *d*=250 nm. The parameter is the mesa width *W*.

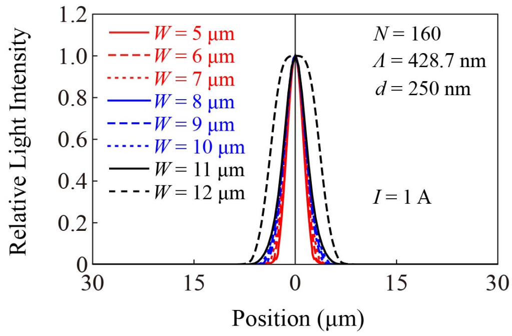

Fig.5 Near field patterns for the fundamental horizontal transverse mode. The parameter is the mesa width.

Figure 4 shows the wall-plug efficiency versus the injected current when *N*=160, Λ=428.7 nm, and *d*=250 nm. The parameter is the mesa width *W*. With an increase in *W*, the wall-plug efficiency decreases. It should be noted that when kink appears in the *L-I* curve the wall-plug efficiency reduced to about half of that of kink-free operation.

Figure 5 shows the near field patterns (NFPs) for the fundamental horizontal transverse mode when the injected current *I* is 1 A. The parameter is the mesa width *W*. FWHMs are in the range between 3.0 μm and 4.0 μm when 5 μm ≤ *W* ≤ 11 μm with kink-free operation and FWHM is 7.5 μm when *W*=12 μm with kink.

IV. CONCLUSIONS

Ridge-type semiconductor lasers with transversal diffraction gratings were simulated, and kink-free operation was obtained up to the injected current of 3 A for a wide mesa up to 11 μm.

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