International Conference on Space Optics—ICSO 1997

Toulouse, France

2–4 December 1997

Edited by George Otrio

A new concept of flared amplifier for high brightness source

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International Conference on Space Optics — ICSO 1997, edited by Georges Otrio, Proc. of SPIE Vol. 10570, 105702I · © 1997 ESA and CNES · CCC code: 0277-786X/18/\$18 · doi: 10.1117/12.2326644

Proc. of SPIE Vol. 10570 105702I-1

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ABSTRACT - A new concept of flared amplifier in which the electrode is longitudinally divided into two sections is presented. The performance of this new amplifier is theoretically reviewed relative to the conventional one-section flared amplifier. The signal-to-noise ratio and the M^2 factor of the output field characterize the quality of each device: the results show that for the same quality criteria the two-section amplifier offers twice as much greater output power as the one-section device.

1 - INTRODUCTION

High-power diffraction-limited semiconductor sources have attracted considerable attention owing to the variety of potential applications for space. They could be used as transmitters in optical communication systems, pumps of fibre amplifiers, or solid state lasers for lidars, remote sensing and countermeasures. Single-lobed diffraction-limited beam and power in excess of 1W have been obtained with a master-oscillator power-amplifier (MOPA) approach, using a distributed Bragg reflector (DBR) laser oscillator coupled into a tapered-contact amplifier, either in a discrete [Kint 93, Yeh 93, Mehu 93, Donn 96], or a monolithically integrated form [Park 93, Osin 94, Verdi 95, Obri 97].

Although the benefit of flared amplifiers has been demonstrated, few attempts to improve the design of the device have been reported [Bend 91, Naka 96, Skov 97]. In this paper, a new concept of flared amplifier is proposed consisting of a two-section flared structure, and its superior performance relative to the conventional one-section device is theoretically demonstrated. The quality of the output beam is characterized by the signal-to-noise ratio and the M^2 quality factor of the beam. In the case of the two-section flared amplifier, the output power associated with the same beam quality criteria is more than doubled.

The basic model is first described and then the simulation results and the proposed structure are presented.

2 - DESCRIPTION OF THE MODEL

Several models have been used to analyze the behavior of high-brightness semiconductor lasers and broad-area amplifiers [Chow 90, Lang 93, Dent 93, Hess 95, Marc 96, Rama 96]. The main purpose of this investigation is to design an amplifier for high-power operation in a stable and near-diffraction limited beam. We propose an advanced configuration of a flared amplifier, less sensitive to the nonlinear mechanisms that limit the output beam quality of the high-power amplifiers.

Our model is based on the beam propagation method that solves wave equation and carrier density distribution simultaneously. The electromagnetic field, assumed to be a monochromatic TE-mode, satisfies the two-dimensional Helmholtz equation, after making the usual effective index approximation. The complex effective index takes into account the effects of carriers on both gain and real index of the structure. The gain is approximated as a linear function of the carrier density, the real and imaginary parts of the active layer index are linked by the antiguiding factor. The carrier density satisfies the diffusion equation which includes nonradiative, spontaneous and stimulated recombinations.

Evolution along the amplifier of the incident lateral beam profile can be entirely described. From the calculated evolution of the lateral optical field profile, the amplifier is characterized by the near- and far-field patterns, the output optical power P_{out} , the efficiency $(P_{out} - P_{in})/P_{elec}$, where P_{elec} is the injected electrical power and P_{in} is the injected optical power, the amplifier gain $G_{dB} = 10 \log (P_{out}/P_{in})$, the "beam quality factor" M^2 and the signal-to-noise ratio P_{out}/P_{ASE} where P_{ASE} is the amplified spontaneous power (ASE). The M^2 factor characterizes the beam shape deviation from a gaussian shape. The power P_{ASE} results from the fraction f of spontaneous emission power amplified during the beam propagation.

3 -SIMULATION OF A CONVENTIONAL FLARED AMPLIFIER

The amplifier considered is 2.5 mm long, with a 7 μm wide gain-guided region input and a 8.4° taper angle. The electrode is divided into two parts, as shown in Fig. 1, which can be independently biased. In this section, we consider the conventional one-section amplifier that corresponds to the particular case where the same voltage is applied to both electrodes. The vertical structure is a AlGaAs/GaAs double heterojunction, with a 0.1 μm thick GaAs active layer and 1 μm Al_{0.3}Ga_{0.7}As cladding layers.

Fig. 1 : Top view of a two-section flared amplifier

The optical properties of both amplifiers are characterized by calculating the output power, the M^2 factor and the S/N ratio. Our quality criteria are defined by an M^2 value below 1.5 and a signal-to-noise ratio up to 100. The input field is Gaussian and is focused to a 2 μm spot at the input facet. Device parameters are listed in Table 1.

Parameter	Symbol	Value	Units
Wavelength	λ	885	nm
GaAs index		3.618	
Ga _{0.3} Al _{0.7} As index		3.380	
Cladding layer resistivity	ρ	0.054	Ohm.cm
Contact layer resistance	r_c	0	
Bimolecular recombination coefficient	B	10^{-10}	cm^3/s
Non-radiative recombination rate	τ_{nr}	5	ns
Differential gain	a	$3 \cdot 10^{-16}$	cm^2
Gain parameter	b	450	cm^{-1}
Carrier density at transparency	N_0	$1.5 \cdot 10^{18}$	cm^{-3}
Antiguinding factor	R_0	-4	
Fraction of ASE	f	10^{-4}	

Table 1: Device parameters

The performance of the one-section flared amplifier is first evaluated. We consider different values of input power equal to 1, 9, 16 and 36 mW, and an applied voltage varying from 1.47 V to 1.51 V corresponding to an unsaturated carrier injection from $1.6 \cdot 10^{18} \text{ cm}^{-3}$ to $2.6 \cdot 10^{18} \text{ cm}^{-3}$. Fig. 2 shows the evolution of the M^2 and S/N values of an amplified optical field along the amplifier for a level of input optical power equal to 9 mW and at several applied voltages. Dotted lines are labelled with constant values of output optical power, and dashed lines with constant amplification length. Following our quality criteria, the highest power achievable at the output of an amplifier can be extracted from the top left-hand quarter of the diagram corresponding to " $M^2 < 1.5$ and $S/N > 100$ ". For a 2.5 mm long amplifier we find a corresponding value equal to 760 mW.

This kind of diagram has been plotted for the different levels of input optical power. Based on the same quality criteria, the highest powers determined in each case are reported in Table 2. No solution exists for an input power level equal to 1 mW. The highest output power achievable with the 2.5 mm long flared amplifier associated with our quality criteria equals 760 mW, and this optical power can be obtained from an input power of 9 mW and an applied voltage of 1.472V. Increasing the input power doesn't yield better results because an excessive input optical power density increases the nonlinear effects which tend to damage the beam shape.

Fig. 2: Evolution of M^2 and S/N along the one-section amplifier for a level of input power equal to 9 mW. Straight lines $M^2=1.5$ and $S/N=100$ define the quality area " $M^2 < 1.5$ and $S/N > 100$ ".
Solid lines : $V = 1.49 \text{ V}$ (1), 1.48 V (2), 1.475 V (3), 1.47 V (4)
Dashed lines : $L = 1 \text{ mm}$ (a), 1.5 mm (b), 2 mm (c), 2.5 mm (d)
Dotted lines : $P = 100 \text{ mW}$ (I), 300 mW (II), 500 mW (III), 700 mW (IV), 900 mW (V)

$P_{in} \text{ (mW)}$	$P_{out} \text{ (mW)}$	$V \text{ (V)}$
1	none	
9	760	1.472
16	700	1.466
36	<600	1.465

Table 2: Highest output powers achievable with the 2.5 mm long one-section flared amplifier and with the " $M^2 < 1.5$ and $S/N > 100$ " quality criteria for several values of P_{in} , and corresponding values of V .

4 - PROPOSAL FOR A TWO-SECTION TAPERED CONTACT

These calculations demonstrate that a fundamental limitation of a one-section flared amplifier lies in the maximum optical input power determined by the quality criteria of the output beam. The input power level, which is in the range of several mW, does not allow us to take advantage of the highest power available from the DBR AlGaAs/GaAs laser diodes. Therefore, we propose the concept of a two-section amplifier which leads to a better control of the level of optical power density along the amplifier thanks to the independent-biased electrodes. Here, the first electrode is not biased ($V_1=0$ V) and provides the advantage of allowing the mode to spread in order to reduce the power density at the input of the second electrode. Thus the first section acts as a "power-adapter" for the second section and plays an important role in reducing the detrimental gain saturation effects on the beam quality. We consider an input optical power after the first section equal to 100 mW corresponding to a level of power available from the DBR AlGaAs/GaAs laser diodes [Majo 93, Majo 94]. The first electrode is 2 mm long while the second is 0.5 mm long. A similar diagram has been plotted (Fig. 3) to determine the highest power achievable at the output of this two-section amplifier: the maximum output power associated with the same quality criteria is about 1.6 W if the applied voltage is 1.505 V. Consequently for the same length of amplifier, the high quality output power has more than doubled in the case of the two-section flared amplifier. Moreover, the injected current equals 4.2 A in this case, which corresponds to a current density of 2.2 kA/cm², against 6.6 A and 1.2 kA/cm² respectively in the one-section amplifier case.

Fig. 3 : Evolution of M^2 and S/N along the two-section amplifier for a level of input power equal to 100 mW and an applied voltage to the first electrode equal to 0 V.
 Solid lines : $V = 1.51$ V (1), 1.50 V (2), 1.49 V (3), 1.48 V (4)
 Dashed lines : $L = 2.2$ mm (a), 2.5 mm (b)
 Dotted lines : $P = 400$ mW (I), 800 mW (II), 1.2 W (III), 1.5 W (IV)

Moreover, the set of a non-biased section between the amplifying section and the master oscillator in a monolithic MOPA device should improve thermal dissipation and provide the advantage of allowing the DBR laser to be independently optimized from the amplifier. Besides, in usual AlGaAs/GaAs devices, the active layer consists of a quantum well structure which leads to better performance than double-heterostructure amplifiers. Quantum-well amplifiers have higher

efficiency, the contribution of thermal effects is thus reduced, the spatial stability of the beam is favored by less important carrier-induced index variations. Therefore a dramatic improvement of the above predicted performance is expected from devices with advanced quantum-well active structures.

5 - CONCLUSION

A new concept of flared amplifier has been proposed which consists in splitting longitudinally the electrode into two sections in order to control the saturation level during amplification. The resulting amplifier exhibits greatly improved theoretical performance respect to the one-section amplifier and would increase the output power of MOPA configurations. Of course, the concept of a two-section flared amplifier can be generalized to a multisection amplifier to make the component adaptable to a large range of input powers and to optimize its performance whatever the master oscillator output power. Furthermore, the simplicity of the concept makes it highly attractive.

ACKNOWLEDGMENTS

This work was performed at LAAS-CNRS of Toulouse. It was supported in part by the Midi-Pyrénées Région and by a grant of the Centre National d'Etudes Spatiales.

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