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PATENT SPECIFICATION

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(19)

(54) OFF-AXIS ALIGNMENT OF STRIPE IN HETEROSTRUCTURE INJECTION LASERS

(71) We, HEWLETT-PACKARD COMPANY, of 1501 Page Mill Road, Palo Alto, California 94304, United States of America, a corporation organised and existing under the laws of the State of California, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention is concerned with off-axis alignment of stripe in heterostructure injection lasers.

Semiconductor stripe-lasers are well known in which stimulated emission results from carrier injection across one or more semiconductor junctions. In multi-layered heterostructure devices one or more recombination regions are bounded by other wider band-gap regions to provide both carrier and optical confinement in the direction normal to the junction plane to a well-defined active region. In order to also limit the active region laterally, current is restricted to a narrow strip typically of the order of 7.5 μm in width. A pair of mirror surfaces is provided perpendicular to the stripe, e.g. by cleaving.

In such devices a certain threshold current is required to be applied to achieve laser action. Ideally the flux-current characteristics of a practical device would exhibit a region of linearity above the threshold current. However, it is now well known in the art that in many semiconductor stripe-lasers the flux-current characteristic curve displays one or more non-linearities, which have come to be known as "kinks". R. W. Dixon et al, have proposed eliminating such kinks in a double heterostructure semiconductor laser by decreasing the width of the stripe (Applied Physics letters 29, No. 6. September 15, 1976). However, decreasing the stripe width causes difficulties in that the threshold current density increases considerably. Other more exotic structures for suppressing kinks have also been proposed, but these appreciably increase the threshold current density required to achieve lasing action and/or decrease production yield.

The presence of kinks in the flux-current characteristics raises difficulties in utilizing such lasers for practical purposes: in particular, modulation of the output is difficult and feedback control based on the laser output tends to produce instabilities in operation.

This invention provides a semiconductor laser comprising, a layer of an N-type semiconductor material; a layer of P-type semiconductor material, said N-type and P-type layers forming a P-N junction in said laser; means for injecting charge carriers across said P-N junction to induce charge recombination and emission of optical radiation; a pair of mirrored faces perpendicular to said P-N junction; and a stripe region adapted to laterally confine charge carrier flow across said P-N junction to a region which is substantially within the lateral boundaries of said stripe region, said stripe region being oriented at an angle in the range $1.1<\theta<4°$ with respect to an axis extending normally between said mirrored faces.

A laser as set forth in the last preceding paragraph may further comprise at least one confinement layer of an N-type semiconductor material; and at least one confinement layer of a P-type semiconductor material; said confinement layers having different band-gaps and optical indices of refraction and being arranged with respect to said P-N junction to confine current and optical flux to a region in the vicinity of said P-N junction.

In a laser set forth in either one of the last two immediately preceding paragraphs, it is preferred that said N-type and P-type layers are of materials selected from GaAs and Al_xGa_{1-x} where $O<x<1$.

In a laser as set forth in any of the last three preceding paragraphs, it is preferred that said stripe region is defined by proton implantation.

There now follows a detailed description which is to be read with reference to the accompanying drawings of a laser according to the present invention; it must be clearly understood that this laser has been selected for description to illustrate the invention by way of example and not by way of limitation.

In the accompanying drawings:—

Figure 1 shows a semiconductor stripe laser in which the stripe axis is inclined to the axis normal to the mirrors;

Figure 2 is a curve of flux-current for a prior art stripe laser, displaying a kink; and

Figure 3 is a curve of flux-current for a stripe laser embodying the invention.

In Figure 1 there is shown a semiconductor double heterojunction laser 11. Faces 13 and 15 are cleaved to act as mirrors, while sides 17 and 19 are scribed or sawn so as to be non-reflective. A center line 21 indicates an axis normal to mirrored faces 13 and 15. As is well known in the art, many detailed semiconductor configurations are available which will function as heterostructure lasers. A number of these are illustrated by M. B. Panish in an article entitled "Heterostructure Injection Lasers" in the Proceedings of the IEEE, Vol. 64, No. 10, October 19, 1976.

Figure 1 illustrates a cross-sectional view of one structure suitable for the practice of the present invention. Region 23 is a metallic contact. Region 25 is an N-type region preferably of GaAs, which is Si doped to about $3\times10^{18}cm^{-3}$. Region 27 constitutes an N-type region about 2.0 μm wide preferably of $Al_xGa_{1-x}As (x\sim.3)$, Te doped to about $3\times10^{17}cm^{-3}$. Region 29 is a P-type layer about 0.2 μm wide preferably of GaAs or $Al_xGa_{1-x}As$ $(O<x<.06)$Ge doped to about $4\times10^{17}cm^{-3}$. Region 31 is another P-type layer about 1.0 μm wide, preferably of $Al_xGa_{1-x}As$ $(x\sim.3)$, Ge doped to about $4\times10^{17}cm^{-3}$. Region 33 is another P-type layer about 1.0 μm wide, preferably of GaAs, Ge doped to about $2\times10^{18}cm^{-3}$. Finally, region 35 constitutes a suitable contact, such as a Zn diffused layer contacted with TiPt. Generation of light results from recombination of charge carriers primarily in region 29 adjacent to the P-N junction between N-type region 27 and P-type region 29. Both current and optical flux are confined to this region by virtue of the wider band gap and higher index of refraction of the adjacent layers.

To confine the light laterally, current flow is restricted to a narrow stripe 41. In the preferred embodiment the stripe 41 is defined by proton bombardment of two regions 37 and 93 to form high resistivity regions in the GaAs and $Al_xGa_{1-x}As$ layers 31 and 33. Thus, current flow is essentially confined laterally to the striped region 41 between the regions 37 and 39. The stripe 41 may also be defined in other ways known in the art such as by oxide confinement or junction confinement. In working devices the width of the stripe 41 has been in the range 2.5 μm to 15 μm with a preferred width of about 7.5 μm.

In prior art devices of this kind the stripe 41 has been oriented along the center line 21 normal to the mirrors 13 and 15. As was discussed above however, such devices display undesirable kinks in the laser flux-current characteristics. A curve labelled 45 in Figure 2 displays such a non-linearity in flux at an injection current to about 120 mA. Additionally, it has been observed that the spatial location of the emitted radiation shifts as the current is increased through the kink region. This effect has been attributed to a shift in position of a filament within the stripe region in which the lasing actually occurs.

According to the principles of the present invention the stripe 41 should be oriented along another axis 43 rotated through an angle θ with respect to the center line 21. For the geometry discussed above angles in the range $1.1°<\theta<4°$ have provided good results, with $\theta=2°$ being preferred. With this orientation light emerges from the mirrored ends of the device at an angle of 7° from the center line 21. The off-axis alignment described above was achieved in the preferred embodiment by simply aligning the mask governing proton implantation at the desired angle with respect to the mirror center line 21.

The optical flux for a device constructed according to the preferred embodiment described above is shown in Figure 3; curve 47 is free of non-linearities up to flux values higher than that for the onset of kinks in equivalent devices which do not embody the invention. Additionally, in devices according to the invention, the spatial location of the emitted radiation remains stable over a wide range of values of output flux.

WHAT WE CLAIM IS:—

1. A semiconductor laser comprising: a layer of an N-type semiconductor material; a layer of P-type semiconductor material, said N-type and P-type layers forming a P-N junction in said laser; means for injecting

charge carriers across said P-N junction to induce charge recombination and emission of optical radiation; a pair of mirrored faces perpendicular to said P-N junction; and a stripe region adapted to laterally confine charge carrier flow across said P-N junction to a region which is substantially within the lateral boundaries of said stripe region, said stripe region being oriented at an angle in the range $1.1° < \theta < 4°$ with respect to an axis extending normally between said mirrored faces.

2. A semiconductor laser according to claim 1 of the heterostructure type, further comprising: at least one confinement layer of an N-type semiconductor material; and at least one confinement layer of a P-type semiconductor material; said confinement layers having different band-gaps and optical indices of refraction and being arranged with respect to said P-N junction to confine current and optical flux to a region in the vicinity of said P-N junction.

3. A semiconductor laser according to either one of claims 1 and 2 wherein said N-type and P-type layers are of materials selected from GaAs and $Al_xGa_{1-x}As$, where $O<x<1$.

4. A semiconductor laser according to any one of the preceding claims wherein said stripe region is defined by proton implantation.

5. A semiconductor laser substantially as herein described with reference to Figs. 1 and 3 of the accompanying drawings.

HEWLETT-PACKARD COMPANY

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3 SHEETS This drawing is a reproduction of the Original on a reduced scale
Sheet 1

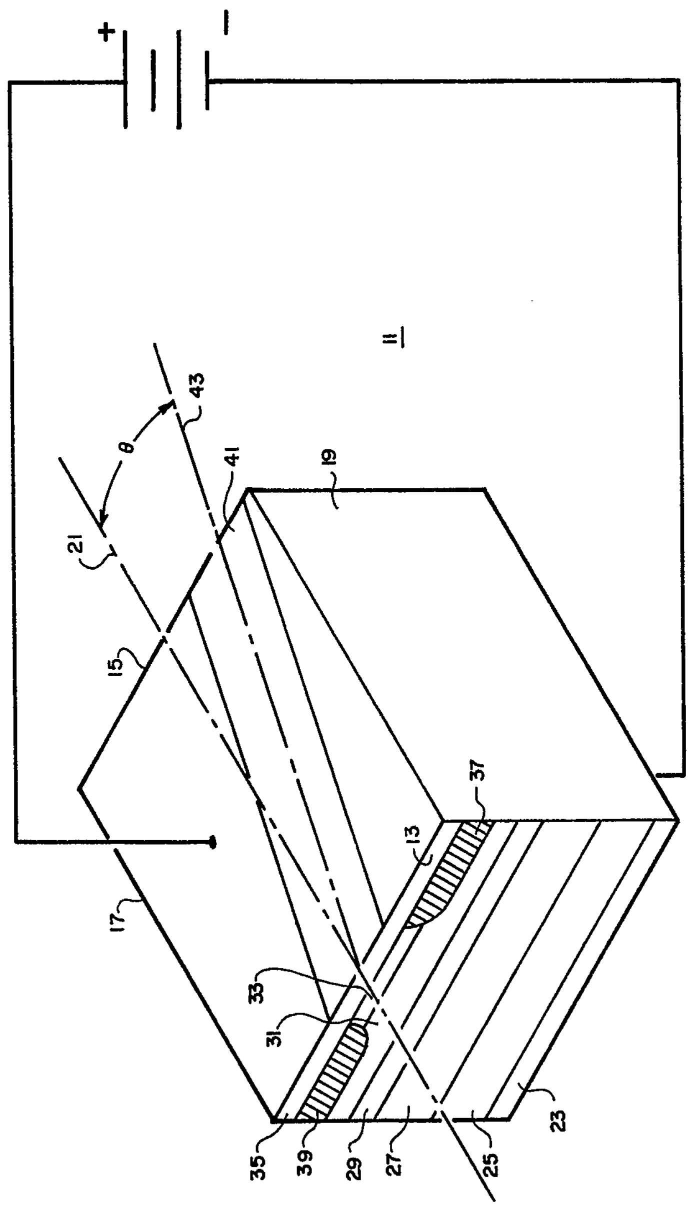

Figure 1

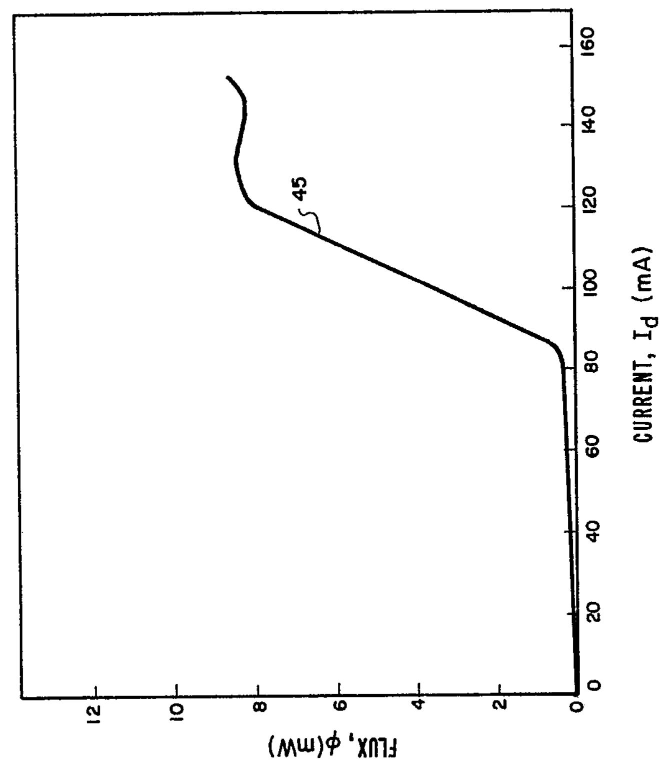
FLUX, φ(mW)
0
2
4
6
8
10
12
CURRENT, I_d (mA)
0
20
40
60
80
100
120
140
160
45

Figure 2

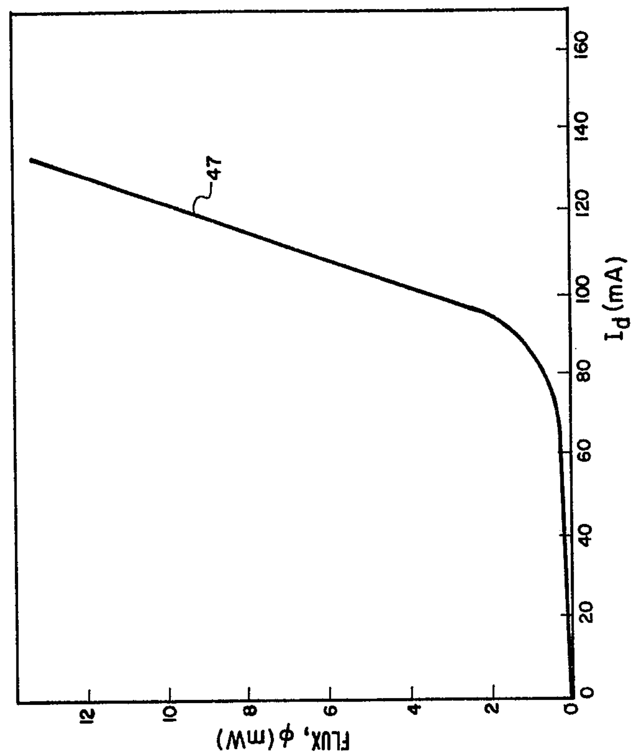

Figure 3