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AD-A222 932

R & D STATUS REPORT #5

DARPA Order No.	:	6325
Contractor	:	Ortel Corporation
Contract No.	:	N00014-88-C-0483
Contract Amount	:	$708,516.00
Effective Date of Contract	:	18 July 1988
Expiration Date of Contract	:	30 September 1990
Principal Investigator	:	Dr. Michael Mittelstein (current) Dr. Nadav Bar-Chaim (initially)
Telephone No.	:	(818) 281-3636
Title of Work	:	"Vertical Emitting, Ring Geometry, Ultra-low Threshold and Ultra-high Speed Quantum Well Lasers for Optical Interconnect"
Reporting Period	:	March 1990 - May 1990

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March 1990 - May 1990

The following constitutes the quarterly report for work done on Contract No. N00014-88-C-0483 entitled "Vertical Emitting, Ring Geometry, Ultra-low Threshold and Ultra-high Speed Quantum Well Lasers for Optical Interconnect".

The main emphasis during this quarter was placed on the following efforts: 1) development of a ridge wave guide as an alternative lateral optical guiding structure; 2) investigation of the ridge wave guide structure in ring configuration; 3) single quantum well material investigation.

Ridge Wave Guide Structure, a Comparison with Buried Heterostructure

Similar to the buried heterostructure the ridge wave guide structure depends on etching a pattern for lateral guiding vertically into the stack of layers provided by a first growth.

The buried heterostructure requires a very narrow mesa of 1 to 1.5 μm width at the height of the active region. Wider structures do not suppress multi-mode operation unless the second growth which is buries the mesa, is very closely matched in material composition (in our case Al-concentration) to the first growth material. The very tight requirement is difficult to achieve with the very deep etch performed (typically 4 µm in our case). With straight lasers only one crystallographic orientation is encountered, but for the ring structure different crystallographic orientations are an inherent complication. While the narrowness of the active region and the wave guide is theoretically advantageous for small radius bends, the experimental finding indicates no lasing for the tested 50 µm radius devices. The theoretical advantage is only realized if the wave guide is narrow in all the orientations appearing in the resonator, if in some orientations the width is exceeding the limit the ring resonator becomes leaky and low threshold lasing from a single quantum well active region is not achieved.

The ridge wave guide structure, in contrast, relies on a shallower etch, 1 to 1.5 µm deep. This material removal results in a modified vertical waveguide such that an effective real lateral waveguide is established without subsequential material deposition. A more indepth treatment should utilize a two-dimensional approach because the interaction of the transverse and lateral effects. In any event, the resulting structure does not utilize a second regrowth and therefore has the potential to be realized with higher reproducibility. Typical sizes of the mesa structure are 2 to 5 µm width at the top of the mesa. The advantage of this structure is that the three-fold reduction in etching depth results in a approximate three-fold reduction in the orientation dependent width of the etched structure. The results obtained regarding this parameter are described in the next paragraph. The vertical etching in the ridge waveguide structure is carried close to the active region. The distance to the active region in the order of 0.2 to 0.5 μm has to be obtained with high precision for reproducibility. The experimental approach chosen is described in the next paragraphs.

Ridge Waveguide Structure, the Experimental Approach

The experimental approach to investigate ridge waveguide laser structures was based on two sets of experiments. On one hand, a stop-etch layer technique was utilized to implement built-in high degree of control on the processing and on the other hand, a simple single etching was performed using a set of etching times to select the optimum etch depth afterwards.

The stop-etch layer technique is based on a modified vertical structure provided by a special wafer growth. The modification is an additional layer introduced so that the overall properties of the optical waveguide are compromised minimally. Broad area lasers were fabricated to verify the material quality. Within the variations of devices, the material matched the properties of our standard material. Hence, no significant degradation occurred. A properly designed process allows us to use the additional layer to slow-down the etching speed when performing the vertical etch. Consequently, the surface to which the etch is to be performed is planarized. More importantly, because the depth at which the etch stops (or slows down) is controlled by the layer structure. Reduced sensitivity with regard to the possible variations of layer thickness of the material to be removed is obtained. In our case, the structure incorporates a 0.1 Al-content layer of 0.1 μm thickness placed 0.3 μm above the active region. This layer is about 1.3 μm below the original top surface of the structure. A conventional etch is utilized to etch close to the stop etch layer without actually reaching it. Then a highly selective etch that we have developed previously is used to remove the remaining material above the stop etch layer. Even extended etch times do not result in penetration of the stop etch layer. As a result, the structure exhibits a remaining layer thickness above the active region of uniform thickness determined mainly by the original growth of the layers and very little by the actual etching process. Actually, the process is more involved: The top most layer, which is the contact layer, is GaAs which is not etched by the selective etch. If no selective removal is performed, this layer will be undercut and the overhanging material will make top contact metallization difficult. Consequently, we performed three etch steps utilizing two photoresist masks for the stop etch layer process. Also the width of the ridge waveguide was varied and very narrow up to about 6 μm wide ridges were fabricated for subsequent investigation.

As an alternative approach a simple ridge waveguide process was investigated. In this case, the a single photoresist masking step dependent etch-depth was determined on small test pieces of the wafer. Then the remaining wafer was divided in three pieces, one of which was etch at the previously determined optimum time, the other two where etched slightly shorter and slightly longer respectively. Thereafter, lasers made from material of all three etch times were investigated.

Ridge Wave Guide Structure, Experimental Findings

The experimental findings are similar for the best devices of both runs. Threshold currents for 1000 μm long devices are near 35 mA and the slope efficiencies for uncoated devices reached 0.45. With both methods we are able to fabricate good ridge waveguide lasers, however, for the simple method we wasted two thirds of the material. Actually the etch time considered optimum resulted in the best lasers. The longer etching time resulted in less favorable far field pattern, as expected for to strong of a guide. The results regarding the width of the ridge which was varied in the stop etch layer experiments indicate, that near 4 μm width gives the best far field pattern. Consequently our 5 μm width ridge wave guide lasers from the simple etching experiment are wider then optimal.

Ridge Waveguide Ring Structure Investigation

In order to see if the etching process qualifies for ring structure ridge waveguide fabrication etch test were performed and investigated. The etching depth was increased in order to enhance the variation caused by the different crystallographic orientations. Starting from a 8 μm wide silox mask a ring mesa with a width at the top of 2.5 to 3 μm was obtained. The measurement was performed in a SEM to obtain high relative accuracy and resolution. This 0.5 μm variation is expected to be reduced to 0.3 μm if the etching time is scaled for ridge wave guide fabrication. Furthermore, the chip was cleaved in the to perpendicular directions and broken in the intermediate direction to investigate the cross section of the mesa. The preliminary finding looked very promising in that the profile seen in the SEM exhibits very little of the undercutting usually obtained in the dove-tail direction. The overhang is approximately 0.1 μm and limited to the to 0.5 μm of the etching depth. The optical mode has very little intensity at this location. This is a significant finding, because the undercut is not only creating problems for the contact metallization but increases the losses for the optical wave.

Single Quantum Well Material Investigation

We have observed that the broad area lasers we use for material characterization degrade significantly in the course of several hours of CW operation. The more complicated structures utilized to perform for the special properties considered in this contract only mask the underlying problem of the material. Consequently, investigations on the properties of our single quantum well structures were started on broad area lasers. The degradation appeared primarily in the CW light verses current curve (L-I) as well as to a lesser degree in the pulsed L-I . Increased device heating could cause this behavior, so thermal impedance and contact resistance were investigated as possible causes. Experiments were performed to improve the contacts. As a result, the p-contact metal thickness was changed to now use a 200 Å Cr layer followed by and mediated second evaporation of 2500 Å Au. Also a new cleaning procedure was instituted before p-contact metalization. Contact resistance was measured to be 300 Ohm per square micrometer. With persisting degradation, attention was given to electron induced current (EBIC) measurements. Also lasers were operated for extended time just below threshold to current stress them but eliminate optical damage. On the other hand, devices were stored at high temperature and no degradation was found. In conclusion, the problem seemed to be either current or electric-field induced.

Another investigation involved strain resulting from the silox-semiconductor interface in the oxide stripe lasers. Lasers were fabricated with different degrees of strain in the silox layer by varying the thickness. Also a wafer was grown with a n-type blocking layer replacing the silox altogether. For degradation evaluation of devices fabricated with these modifications, a new fixture has been designed -- its description follows below.

These material investigations are ongoing and will improve the single quantum well material used for the vertically emitting lasers.

A fixture has been designed and built to hold up to eight lasers in a casette. The devices are connected in series and are driven by a current supply rated at 5 A and 35 V in order to drive these large structure test devices. A detector is mounted on a side and can be positioned in front of each device to measure its output power. To characterize the degradation, lasers will be operated at constant current and the power be recorded at regular intervals.

Other Activities

The paper for publication in a technical journal has been accepted for publication in Applied Physics Letters and we are in the process to finalize it.