# COMPEL - The international journal for computation and mathematics in electrical and electronic engineering

OPTICAL POWER COUPLING IN SYMMETRIC TRIANGULAR PERIODIC STRUCTURES

V.Jayan P.R.Vaya

COMPEL - The International Journal for Computation and Mathematics in Electrical and Electronic Engineering
Vol 10, No 4, 355-362 (c) James & James Science Publishers Ltd

# OPTICAL POWER COUPLING IN SYMMETRIC TRIANGULAR PERIODIC STRUCTURES

V.Jayan and P.R.Vaya
Semiconductor Device Research Lab.
Centre for Systems and Devices
INDIAN INSTITUTE OF TECHNOLOGY
MADRAS- 600 036

## Abstract:

SEM picture of rectangular gratings realised by chemical etching mostly resembled a triangular grating.Symmetric triangular gratings can give better directionality to the DFB laser beam.In this communication,the optimal Bragg order,grating period and tooth height,active layer thickness were presented from a study of the optical power coupling for a symmetric triangular GaAs-AlGaAs structure.The numerical parameters so obtained were compared to the reported results and found that chemically etched rectangular grating obeys the theory of symmetric triangular grating with remarkable accuracy.

## 1.Introduction

Kogelnik and Shank[1] conceived the idea of DFB lasers in early seventies,the area has grown in a tremendous fashion thereafter[2] and is of current interest[3].A judicious selection of tooth shape and heights will realise better directionality which is essential for laser devices. The corrugations at the dielectric interface can be of a veriety of shapes like sinusoidal,rectangular, triangular,sawtooth etc. The fabrication and analysis of DFB lasers employing rectangular gratings are widely reported. Many authors pointed out that the SEM pictures of fabricated rectangular gratings showed a triangular profile.[4,5]as a result of chemical etching. The analysis of Peng and Tamir [6] on blazing effects based on grating structure showed better suitability of symmetric triangular or sawtooth structure for DFB operation. However little significant work has been reported on the design aspects of DFB lasers employing these structures. In this communication an attempt have been made to evolve the approximate design parameters for a GaAs-AlGaAs DFB waveguide through a study of the dependence of optical power coupling on various wave guide parameters by considering a symmetric triangular structure.

## 2.Computational approach

Yariv has proposed a theory for the coupling of optical power ($|K|$) in a periodic waveguide by considering the full guide width in the calculation of unperturbed E-field [7]. However, later reports showed that this approach led to inaccurate results [8]. Therefore to overcome this, Streifer et al have modified Yariv's expression by employing a guidewidth less than the actual one in the periodic structure [9]. This approach has found a reliable validity as reported by other workers [eg.10]. We have considered a three layer DFB waveguide as shown in Fig.1 to calculate $|K|$ in a waveguide with symmetric triangular gratings.

The coupling of power between the counter running waves for TE fundamental mode in such a structure was computed using the following expression given by Streifer et al:

$$K = \frac{k_0^2 (n_1^2 - n_2^2)\, g}{4\pi m \beta N^2}$$

$$\Big\{\Big(1 + \frac{q^2}{h^2}\Big) \frac{[1 - \cos(\pi m/2)]}{\pi m}$$

$$+ \frac{q}{h} \frac{2}{[(2gh)^2 - (\pi m)^2]} [2gh \sin(\pi m/2)$$

$$- \pi m \sin(gh)]$$

$$- \Big(1 - \frac{q^2}{h^2}\Big) \frac{\pi m}{[(2gh)^2 - (\pi m)^2]} [\cos(gh)$$

$$- \cos(\pi m/2)]$$

$$- \frac{2(-1)^m}{[(2gq)^2 + (\pi m)^2]} [2gq \sin(\pi m/2)$$

$$- \pi m \cos(\pi m/2) + \pi m e^{-gq}]\Big\} \qquad (1)$$

where $q = (\beta^2 - n_1^2 k^2)^{1/2}$

$h = (n_2^2 k^2 - \beta^2)^{1/2}$

$p = (\beta^2 - n_3^2 k^2)^{1/2}$

$$N^2 = \frac{(h^2 + q^2)(t^{-1} + q^{-1} + p^{-1})}{2h^2}$$

$$\beta = \frac{\pi m}{w}\ ; \quad k_0 = \frac{2\pi}{\lambda_0}\ ; \quad k = \frac{\omega}{c}$$

$w$ and $g$ are the period and tooth height of the grating

respectively, m is the Bragg order, $n_1$ and $n_3$ are refractive indices of confinement layers, $n_2$ and t are refractive index and thickness of active layer respectively and $t^1 = t - g$.
And also from reference [2] the reflection coefficient can be written as

$$R_{\emptyset} = \tanh^2(|K|L) \qquad (2)$$

A FORTRAN program was written to solve these equations on a PC by iterative method. This is used to get design parameters like bragg order, grating period etc. for GaAs- AlGaAs double heterojunction distributed feedback laser waveguide as a test case.

From the coupling coefficient we computed the length of the cavity L, for maximum reflectivity and total number of periods for the same by using expression (2).

## 3.Results

It is important to find out the bragg order at which the grating can give optimal coupling. Here the effect of different Bragg orders (m = 1,2,3,4 and 5) on coupling coefficient were studied for different periods and tooth heights ranging from 0.15 - 0.39 um and 0.01-0.29 um respectively by considering a constant active layer thickness. For the first order grating (Fig.2), it was found that the coupling coefficient increases linearly with period for a given tooth height. Here we plotted only for six typical tooth heights. In the case of second Bragg order (Fig.3) the coupling coefficient shows non-uniform coupling variation for periods less than Ø.2 um and vanishes at Ø.25 um irrespective of the tooth height. For periods greater than Ø.3 um the coupling of power was fairly uniform which suggests the suitability of second Bragg order reflection which is in good agreement with results [5,11]. It is evident from the graph that the numerical values of coupling coefficients are more or less constant for periods around Ø.33 um and tooth heights around Ø.21 um. This information points towards the optimal value of grating period and tooth height. These values are in good agreement with the reported values for the rectangular structure designed for m=3 [12]. The difference in value of m might be due to the dependence of effective refractive index on the shape of the grating. As the SEM picture of the resultant rectangular grating obtained by chemical etching more or less resembles a triangular structure justifies the value of m=2 [12]. This is also in total agreement with the observations of other workers as mentioned in the introduction [4,5]. The vanishing of coupling coefficient |K| can be attributed to the distructive interference of the counter running waves within the cavity. We repeated the iteration for m=3,4 and 5 the results of which showed that the number of coupling coefficient minima points increases with order which is undesirable in the laser action. These results were true for all active layer thicknesses considered.

Considering the second Bragg order and a period

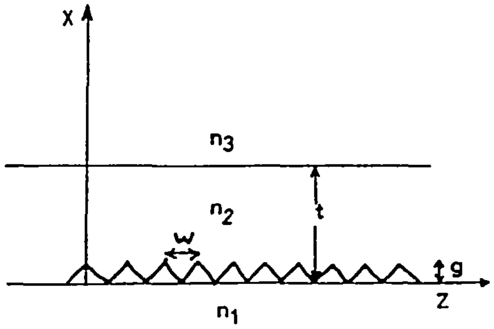


Fig.1 Basic three layer DFB waveguide structure

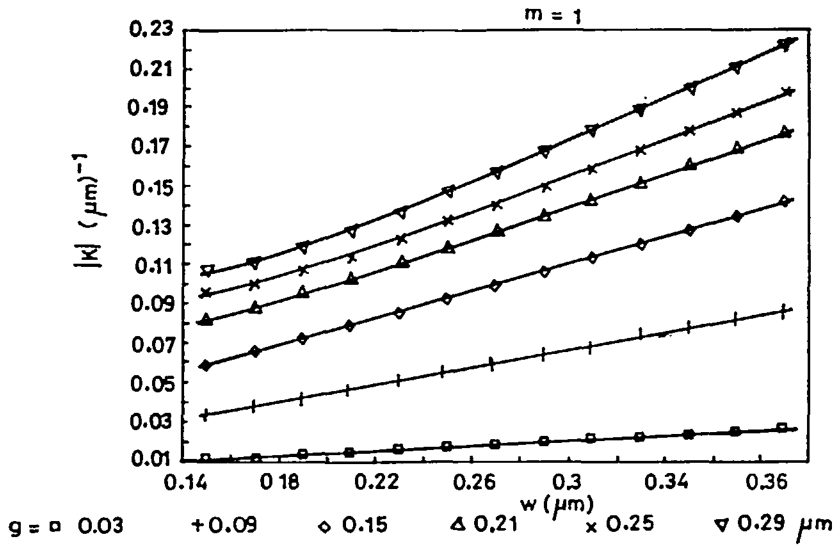


Fig.2 Coupling coefficient vs Grating period for different grating tooth heights for first Bragg order.

of Ø.33 um for uniform coupling as suggested above,we studied the effect of active layer thickness also on coupling coefficient for different tooth heights.For this, the active layer thickness was varied in the range of Ø-2.9 um. The coupling coeffcient followed an exponential decrease with active layer thickness. For active layer thicknesses upto 1 um, |K| showed a rapid decrease. Above 1 um the effect of active layer thickness in the transfer of power was less. We repeated the iteration for t = Ø-Ø.4 um alone. The results showed non-uniform coupling of power in the range t = Ø-Ø.2um which suggests the less suitability of the range. It was obvious from Fig.4 that an increase in tooth height beyond a limit will not yield better results as the |K| values were essentially the same in g=Ø.21-Ø.29 um range. In order to realise high coupling between the counter running waves an active layer of thickness between Ø.2 and 1 um can be selected which is in agreement with the observed results [12]. A comparison of our numerical results for symmetric triangular periodic structure to that of reported results for rectangular structure obtained by chemical etching are given in table 1.

Table 1 A comparison of our results for symmetric triangular structure with the reported results for rectangular periodic structure.

| No | Parameter | Sy.triangular structure (present work) | Rectangular structure [Ref] |
|---|---|---|---|
| 1 | Bragg order | 2 | 3 [12] |
| 2 | Grating period(um) | ~Ø.33 | Ø.34 [ " ] |
| 3 | Grating tooth height(um) | ~Ø.21 | Ø.18 [ " ] |
| 4 | Active layer thickness(um) | Ø.2-1.Ø | Ø.8Ø [ " ] |

So far the refractive index of active and confinement layers were considered as constant and we saw that for a period of Ø.25um the coupling coefficient became zero. To see the possibility of making it a useful period in the second Bragg order,iteration had been carried out by considering the variation in refractive index of the confinement layer in the range 3.4-3.6. The results showed that (Fig 5) coupling coefficient is zero at a confinement layer refractive index of 3.6 and is maximum at 3.48. So by choosing the mole fraction x properly in $Al_xGa_{1-x}As$ confinement layers it is possible to achieve non-zero coupling irrespective of active layer thickness.

After fixing the parameters like grating period,tooth height etc. for getting the optimum coupling coefficient one can obtain the cavity length using eqn (2) for a typical

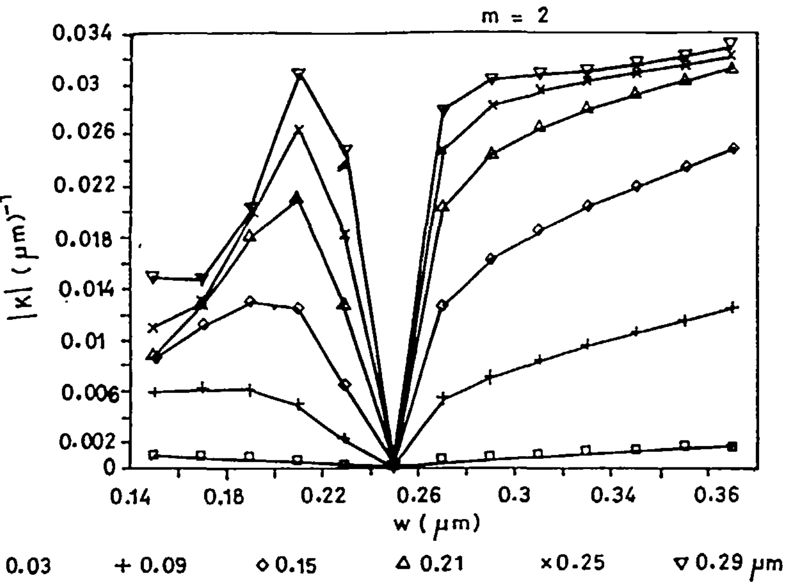


Fig.3 Coupling coefficient vs Grating period for different grating tooth heights for second Bragg order.

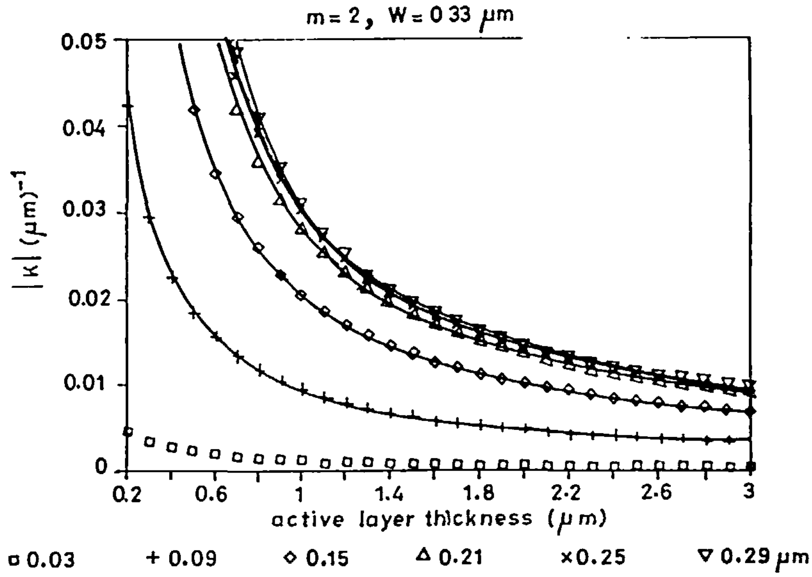


Fig.4 Coupling coefficient vs Active layer thickness for w = Ø.33 um and m=2.

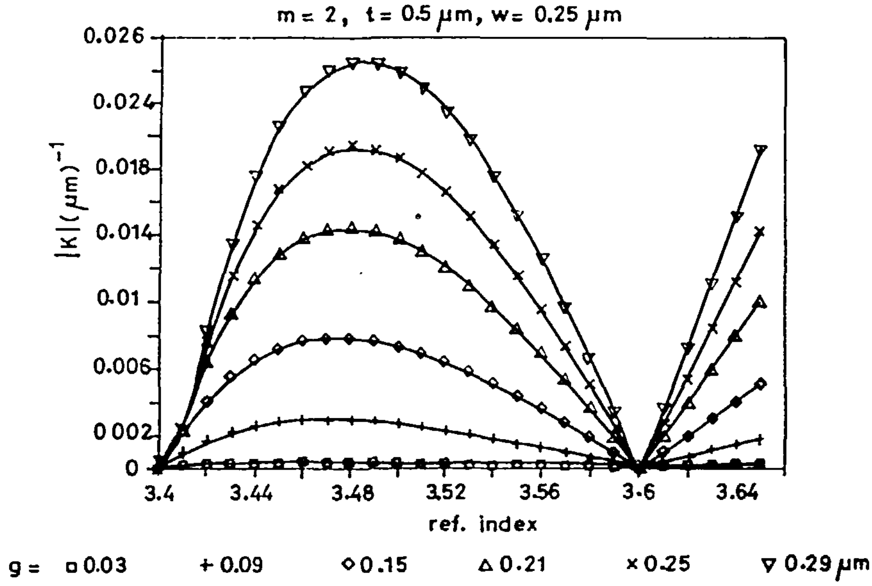


Fig.5 Coupling coefficient vs Refractive index of the confinement layer for m=2,t = Ø.5 um and w = Ø.25 um

reflection coefficient and hence the total number of periods in the waveguide.

## 4. Conclusions

A periodic wave guide structure of current interest was analysed to evolve the approximate design parameters through a study of optical power coupling with respect to symmetric triangular grating. The optimal Bragg order, grating period and tooth height and active layer thickness obtained were presented which are in agreement with the reported results of rectangular gratings obtained by chemical etching. This was attributed to the observed deviation of the rectangular grating profile during the etching process.

## References

[1] H.Kogelnik and C.V.Shank, J.Appl.Phys.,Vol.43, pp 2327-2335, 1972
[2] A.Yariv and M.Nakamura, IEEE J.Quantum Electron.,Vol.13, pp 233-253,1977
[3] H.Sato and Y.Hori,IEEE J.Quantum Electron.,Vol.26, pp 467-472,1990
[4] Ghizoni et al., IEEE J.Quantum Electron.,Vol.12,p 69 1976
[5] R.F.Kazarinov and C.H.Henry,IEEE J.Quantum Electron., Vol.21,pp 144-150,1985
[6] S.T.Peng and T. Tamir, Opt. Commun.,Vol.11,pp 405-409, 1974
[7] A.Yariv,IEEE J.Quantum Electron.,Vol.9,pp 919-933, 1973
[8] K. Handa et al, Appl.Phys.,Vol.5,p 325, 1975.
[9] W.Streifer et al.,IEEE J.Quantum Electron.,Vol.11, pp 867-873,1975
[10] Y. Yamamato et al., IEEE J.Quantum Electron.,Vol.14, pp 245-258,1978
[11] C.H.Henry et al.,IEEE J.Quantum Electron.,Vol.21, pp 151-154,1985
[12] M.Nakamura et al.,IEEE J.Quantum Electron.,Vol.11, pp 436-439,1975

**This article has been cited by:**

1. J. Qiu, L.H. Liu, P.-f. Hsu. 2010. FDTD analysis of infrared radiative properties of microscale structure aluminum surfaces. *Journal of Quantitative Spectroscopy and Radiative Transfer* **111**:12-13, 1912-1920. [CrossRef]