transverse-mode operation have been achieved at up to 100 mW. At constant *6*, the COD power level is proportional to *LJF*. The same COD power level is obtained because of the same *LJT* values for the two QW structures. It is expected that QW lasers with more than three wells will show even higher power and lower noise because of lower $g_{,h}$ values. However, a decrease in the COD power density for three-well QW lasers was observed.[6] Therefore, the DQW is the most suitable structure for 830 nm high-power QW lasers. Fig. 3 shows the life test results for the DQW lasers for 50°C, 50 mW CW operation. Stable operation for over 1400 h has been obtained.

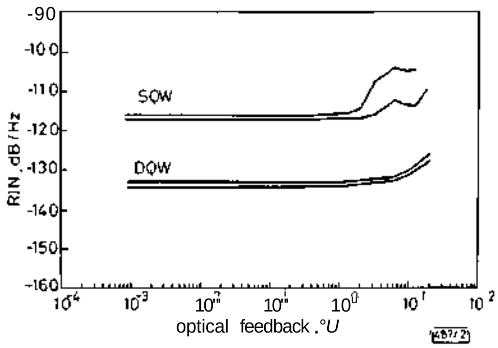

Fig. 2 *Relative intensity noise (RIN) as function of optical feedback ratio for SQW and DQW lasers*

R_f=\0%, R_r = 75%, 0_N ~9°, L = 300/jm, P = 3mW, HF: 650 MHz

In summary, we have successfully developed high-power, low-noise, self-aligned, AlGaAs double-quantum-well lasers for optical disc read/write systems. To obtain a high COD power level with low noise by optical confinement reduction in QW layers, decreasing the threshold gain is important and the introduction of DQW is useful for the purpose.

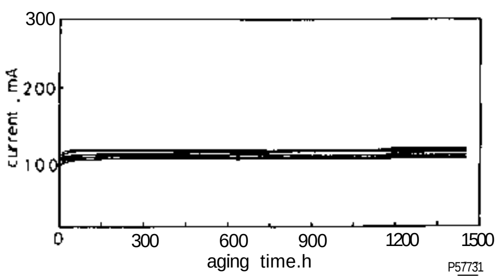

Fig. 3 *Life test results for DQW lasers under 50 mW, CW operation at 50°C*

830 nm, R_f = 10%, R_r = 75%, $0_{,,}$ = 9-12°, *L* = 300/un

We would like to express thanks to H. Kawano and E. Okano for support in regard to the passivation process. We wish to thank M. Sakaguchi and T. Suzuki for their continuous encouragement.

S. ISHIKAWA *17th July 1989*
M. NIDO
K. ENDO
I. KOMAZAKI
K. FUKAGAI
T. YUASA

Opto-Electronics Research Laboratories
NEC Corporation
4-1-1 Miyazaki, Miyamaeku, Kawasaki, Kanagawa 213, Japan

References

1 HOLANYAK, N., JUN., KOLBAS, R. M., DUPU1S, R. D., and DAPKUS, P. D.: 'Quantum-well heterostructure lasers', *IEEE J. Quantum Electron.*, 1980, **QE-16,** pp. 170-186

2 NIDO, M., ENDO, K., ISHIKAWA, S., UCHIDA, M., KOMAZAKI, I., HARA, K., and YUASA, T.: 'High power and low optical feedback noise AlGaAs single quantum well lasers', *Electron. Lett.*, 1989, 25, pp. 277-278

3 ARAKAWA, Y., and YARIV, A.: "Quantum well lasers—gain, spectra, dynamics', *IEEE J. Quantum Electron.*, 1986, **QE-22,** pp. 1887-1899

4 WILCOX, J. Z., PETERSON, G. L., OU, S., YANG, J. J., and JANSEN, M.: 'Length dependence of threshold current in multiple quantum well lasers', *Electron. Lett.*, 1988, 24, pp. 1218-1220

5 ARNOLD, G., and PETERMAN, K.: 'Intrinsic noise of semiconductor lasers in optical communication systems', *Opt. & Quantum Electron.*, 1980, **12,** pp. 207-219

6 ISHIKAWA, S., *et al.*: to be published

COUPLED MODE ANALYSIS OF FINLINES ON ANISOTROPIC SUBSTRATES

Indexing terms: Microwave devices and components, Waveguides, Microwave radiation

Coupled mode theory has recently been applied to study finlines loaded inhomogenously with a dielectric or a ferrite. In this letter we report the results of the application of the coupled mode theory to obtain the propagation constants of finlines on anisotropic substrates.

Introduction and theory: The generalised telegraphist's equation method,[1] also known as coupled mode theory, is a rigorous method of studying uniform waveguides containing general anisotropic media.[2-4] It can be applied to finlines as well, and as noted in Reference 5, has the advantage of being applicable to cases which cannot be studied using the spectral-domain method. In References 5-6, the applicability of coupled mode theory to finlines is demonstrated for the cases of finlines containing (a) a lossy dielectric and *(b)* a magnetised ferrite. In this letter we demonstrate the applicability of coupled mode theory to obtain the propagation constants of unilateral and bilateral finlines on anisotropic substrates. We confine our study to low dielectric materials as has been done in Reference 5. For these cases, it has been found sufficient to include only TE modes of the finned guides in the telegraphic equations. The permittivity tensor of the anisotropic substrate has been assumed to be of the form

$$\bar{\varepsilon} = \varepsilon_0 \begin{bmatrix} \varepsilon_{xx} & 0 & 0 \\ 0 & \varepsilon_{yy} & 0 \\ 0 & 0 & \varepsilon_{zz} \end{bmatrix}$$

where ε_0 = permittivity of vacuum.

For the unilateral finline shown in Fig. 1, the TE mode potentials $T_{[m]}$ in region I of the corresponding finned guide can be written as (with the origin at the fin)

$$T_{[m]} = Y_i^R T \cosh it_i''(d_2 + xj] \cos (k_t y) \quad (1)$$

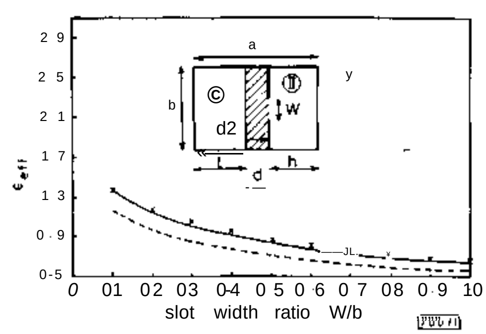

Fig. 1 *Unilateral finline*

a = 2*b* = 7112 mm, *t* = *h* = 34935 mm, *d* = 0-125 mm, freq. = 300 GHz
———$\varepsilon_{,,}$ = 3-4, e_{yy} = 5-12
———«« = 2-45, e_{yy} = 2-89
x from Reference 8

where $k_t = 2\pi n/b$, $\Gamma_t^m = (k_t^2 - X_m^2)^{1/2}$ and X_m = cutoff wave number of the mth TE mode.

The cutoff frequencies and the unknown coefficients R_t^m have been obtained using the singular integral equation method similar to the one used in Reference 7. The pertinent telegraphists equations are eqns. 41, 42 and 43 of Reference 1. Using the orthogonality properties of the modes, these equations can be simplified and written as

$$(\beta/k_0)^2 I_{[m]} = [1 - (X_{[m]}/k_0)^2] V_{[m]} + \sum_n \int_W \{(\varepsilon_{xx} - 1)(dT_{[m]}/dy)(dT_{[n]}/dy) + (\varepsilon_{yy} - 1) \times (dT_{[m]}/dx)(dT_{[n]}/dx)\}\, dS \qquad (2)$$

where β = propagation constant, k_0 = free space wavenumber and $X_{[m]}$ = cutoff frequency of the mth TE mode of the finned guide.

The integrals are to be evaluated over the region of the dielectric only. Eqn. 2 is a matrix equation relating the mode coupling coefficients $I_{[m]}$, and by requiring the determinant to be zero we obtain the propagation constant β.

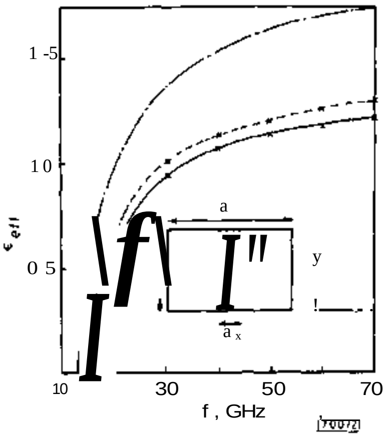

Fig. 2 *Bilateral finline*

$a = 2b = 7{\cdot}112$ mm, $a_x = 0{\cdot}254$ mm, $d = 1{\cdot}0$ mm
——— $\varepsilon_{xx} = \varepsilon_{yy} = 2{\cdot}45$
——— $\varepsilon_{xx} = 2{\cdot}45$, $\varepsilon_{yy} = 2{\cdot}89$
— • — $\varepsilon_{xx} = 3{\cdot}4$, $\varepsilon_{yy} = 5{\cdot}12$
x from Reference 9

Numerical results: Computations have been carried out for unilateral and bilateral finlines and the results are plotted in Figs. 1 and 2. For each of these cases the number of terms used in the series for the mode potentials $T_{[m]}$ is 25. For the unilateral finline case, only one TE mode has been used in the telegraphist's equations, while for the bilateral finline case up to four TE modes have been used. It can be seen that the results obtained using this method agree closely with those published in References 8 and 9, with the maximum deviation being 1·5%. The applicability of coupled mode theory to finlines loaded with more complicated media is currently under investigation.

P. V. RAMAKRISHNA
D. CHADHA

Department of Electrical Engineering
Indian Institute of Technology
Hauz Khas, New Delhi 110016, India

10th August 1989

References

1 SCHELKUNOFF, S. A.: 'Generalized telegraphists equations for waveguides', *Bell Syst. Tech. J.*, 1952, **31**, pp. 784-801
2 MUR, G.: 'A differential equation method for the computation of scattering from an inhomogeneity in a cylindrical waveguide', *J. Eng. Math.*, 1978, 52, (2), pp. 157-175
3 GODSHALK, E. M., and ROSENBAUM, F. J.: 'Nonreciprocal effects in semiconductor loaded waveguides'. IEEE MTT-S, Int. Symp. Dig., June 1984, pp. 455-456
4 XU, Y., and ZHANG, G.: 'A rigorous method for the computation of ferrite toroidal phase shifters', *IEEE Trans. Microw. Theory Tech.*, 1988, **MTT-36,** (12), pp. 929-933
5 MAZUR, J., and MROZOWSKI, M.: 'Coupled mode analyses of finline', *IEEE Trans. Microw. Theory Tech.*, 1989, **MTT-37, (2), pp.** 281-287
6 MROZOWSKI, M., and MAZUR, J.: 'Coupled mode analyses of waveguides containing bianisotropic media', *IEEE Trans. Magn.*, 1988, 24, (3), pp. 1975-1977
7 MITTRA, R., and ITOH, T.: 'A new technique for the analyses of dispersion characteristics of microstrip line', *IEEE Trans. Microw. Theory Tech.*, 1971, **MTT-19,** (1), pp. 47-56
8 AZIZ, A., SHALABY, T. K., and KUMAR, A.: 'Dispersion in unilateral finlines on anisotropic substrates', *IEEE Trans. Microw. Theory Tech.*, 1987, **MTT-35,** (4), pp. 448-450
9 YANG, H. Y., and ALEXOPOULIS, N. G.: 'Uniaxial and biaxial substrate effects on finline characteristics', *IEEE Trans. Microw. Theory Tech.*, 1987, **MTT-35,** (1), pp. 24-29

GaAs/AlGaAs DOUBLE HETEROSTRUCTURE LASER MONOLITHICALLY INTEGRATED WITH PASSIVE WAVEGUIDE USING FOCUSED ION BEAM ETCHING

Indexing terms: Optoelectronics, Integrated optics, Semiconductor lasers, Optical waveguides

We report the fabrication and operation of a double heterostructure (DH) laser butt-coupled to an optical waveguide. A focused ion beam (FIB) is used to fabricate a Perot-Fabry resonator in the monolithic device. Most devices have threshold currents between 90 and 100mA and emit 7mW from the passive waveguide.

Introduction: In the research into optoelectronic integrated circuits (OEICs) the development of monolithic integration between a laser and a transparent waveguide is one of the key issues.[1,2] Recently, we have developed a new monolithic laser-waveguide butt-coupling scheme using a single-step MOCVD.[3] Since in this structure the oscillations occur on the total length of the device (active and passive region)[4] it is necessary to limit the laser cavity to the pumped region and so to define mirrors for the laser.

Structure and FIB system: The structure is illustrated in Fig. 1. The concept of the device based on the butt-coupling technique is reported elsewhere.[4] Different approaches have been considered to fabricate resonators suitable for monolithic integration; in particular focused ion beam etching (FIBE) has produced high-quality laser mirrors.[5] The properties offered by FIBE, such as the absence of masking and the submicrometer focused beam, are well suited to our application, i.e. to obtain a narrow and deep groove. The **FIB** system used in this experiment is composed of a low-energy (20keV) single-lens column coupled with a scanning electron microscope (SEM) built in our laboratory and presented elsewhere.[6]

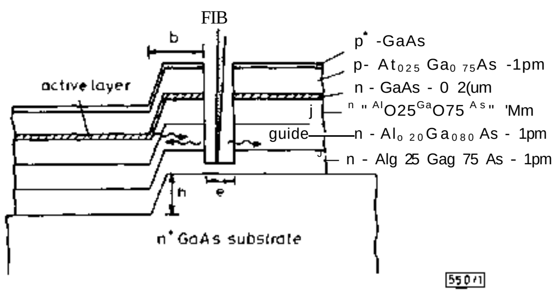

Fig. 1 *Schematic diagram of monolithic device with active layer butt-jointed to optical waveguide*

Groove (width *e)* separates active region from passive region; h = 1·6μm