New measurement technique for waveguide losses based on photoluminescence

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decrease. However, the enhancement in the low-frequency *RIN* which occurs in the absence of cross-saturation is only a few dB and would be too small to explain the experimental results shown in Reference 4. On the other hand, by including the cross-saturation effects with $\theta > \beta$, both low-frequency *RIN* and linewidth peak sharply at a particular output power level. This critical power level P_C is that which minimises $L(0)$ and may be written as

$$P_C \simeq K^{-1}\sqrt{\left(\frac{R_{sp}}{2(\theta - \beta)}\right)}MSR \qquad (8)$$

Using the values in Table 1, this corresponds to a power level of 58 mW at which linewidth and low-frequency *RIN* peak as a function of output power.

This analysis has been performed for a constant value of *MSR*; i.e. the *MSR* does not degrade with increasing power. Rather, as the total power is increased, the side mode power also increases. Note that the expressions for the power levels at which rebroadening begins P_R and reaches a peak P_C depend upon *MSR*. As the *MSR* is improved, the rebroadening is pushed to higher powers and thus may not always be observable. Although we have expressed the linewidth turning points in terms of output power (P_R and P_C), the key parameter is actually the sidemode power. Because a quarter-wave shifted laser stores more photons per mW in the cavity, the sidemode power can be larger than in a conventional laser operating at the same *MSR*.

To summarise, we have shown that the experimentally-observed correlation between the linewidth rebroadening and the low-frequency *RIN* enhancement arises naturally from the rate equations. Without degradation of the *MSR*, the linewidth rebroadens with increasing output power due to carrier-induced mode coupling. The effect of cross-saturation by the sidemode leads to a maximum increase in the laser linewidth and the low-frequency total *RIN*. Both begin to decrease monotonically at still higher output power.

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NEW MEASUREMENT TECHNIQUE FOR WAVEGUIDE LOSSES BASED ON PHOTOLUMINESCENCE

Indexing terms: Waveguides, Losses, Measurement, Photoluminescence

A new technique has been developed to measure optical losses of waveguide devices fabricated in III-V semiconductors by optical excitation of an integrated twinguide structure, which is nondestructive and also applicable to multimode waveguides and multiport waveguide devices. Reproducibility of excitation was found to be better than 0·2 dB.

Introduction: As OEICs are expected to play an important role in future telecommunication systems there is an increasing demand for accurate techniques for measuring the transmission losses of waveguide devices fabricated in III-V semiconductors. Until recently the cutback method was widely applied to this type of measurement. In our laboratory it has been applied for determining the losses of straight and bent InGaAsP waveguides.[1]

A disadvantage of this method is its destructive character. A quick and accurate nondestructive method, which has become increasingly popular, is the Fabry–Perot method.[2] This method is, however, restricted to singlemode two-port devices. We present a nondestructive measurement technique which is applicable to multiport devices with single or multimode waveguides.

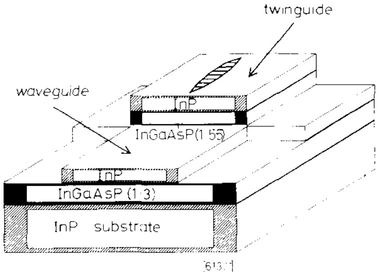

Fig. 1 *Schematic representation of integrated twinguide structure*

Principle: The method is based on optical pumping of an integrated twinguide structure[3] (see Fig. 1). The twinguide consists of a low-bandgap layer [InGaAsP(1.55)] on top of the waveguide layer [InGaAsP(1.3)], separated by a thin InP etch-stop layer. Part of the photoluminescence of the upper quaternary layer ($\lambda = 1{\cdot}55\,\mu$m) will be trapped in the twinguide and propagate in the form of twinguide modes. At the transition between the twinguide and the waveguide section a substantial part of this light is coupled into the transparent waveguide. The light emanating from the waveguide is imaged onto a photodiode. Waveguide attenuation can be measured by fabricating a number of twinguide blocks at different distances from the cleaved edge (Fig. 2). Component losses are measured by comparing the output power with that of a straight waveguide.

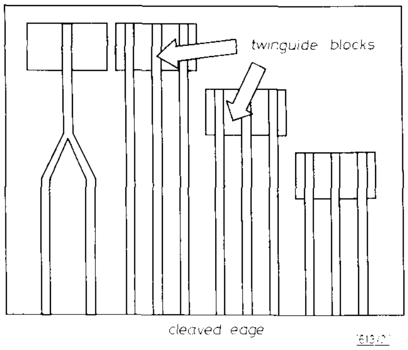

Fig. 2 *Fabrication of twinguides at different distances from cleaved edge allowing determination of waveguide losses*

Experiments: Integrated twinguide structures have been fabricated using MOCVD-grown layers (background doping level < 10^{15} cm^{-3}) on an SI-InP substrate. The layer structure consists of three layers for waveguide fabrication (InP buffer: 1·0 μm, InGaAsP(1·3): 0·4 μm, InP: 0·15 μm) on top of which (in the same epitaxial step) two additional layers (InGaAsP(1·55): 0·2 μm, InP cover: 0·25 μm) are grown for fabrication of the twinguide. Patterning of the integrated twinguide structures was performed by two steps of CH_4/He reactive ion etching at a power density of 0·4 W cm^{-2}. In the first step the two top layers were removed everywhere except at the twinguide sections. In the second step waveguides with a ridge height of 0·55 μm were fabricated in the same way as for nonloaded structures. Fig. 3 shows an SEM micrograph of a fabricated integrated twinguide. Optical pumping was achieved by focusing a stripe on top of the twinguide, using a GaAs/AlGa power laser with a centre wavelength of 820 nm. The light emanating from the waveguides was focused onto a Ge photodiode with a ULWD microscope objective.

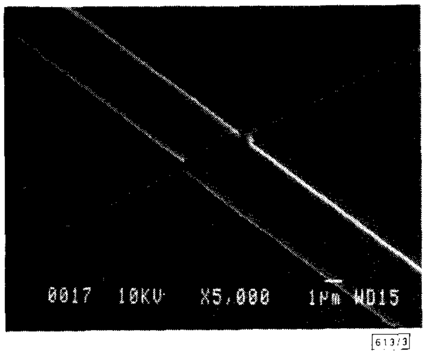

Fig. 3 *SEM picture of integrated twinguide*

Results: Reproducibility of excitation of the integrated twinguide was found to be better than 0·2 dB. The spread in the output intensity of integrated twinguides having identical waveguide lengths is about 0·3 dB. Fig. 4 displays the output power of the integrated twinguide against waveguide length. Waveguide losses are 2·2 ± 0·4 dB/cm and 1·4 ± 0·5 dB/cm for 5 and 7 μm wide waveguides, respectively. Measurements on 50 μm wide waveguides indicate that film losses are negligible.

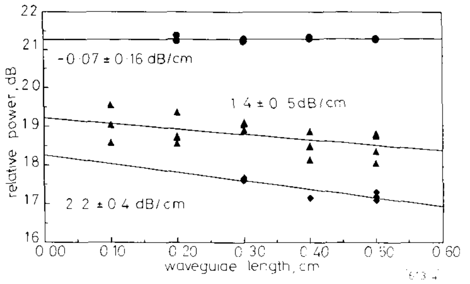

Fig. 4 *Output power against waveguide length for MOCVD integrated twinguides*

◆ 5 μm
▲ 7 μm
● 50 μm

Discussion: The relatively small spread in the output intensity indicates a good excitation reproducibility from one waveguide to another. As a spread of 0·3 dB in transmitted power is quite typical for our waveguides, the actual spread in the power coupled into the waveguides is probably much smaller. The small spread for the 50 μm wide guides seems to confirm this supposition. Measurement accuracy thus compares quite well with existing methods.

In comparison with other methods the present method requires the growth of two additional layers and one additional noncritical etching step. Because the light source is an optically pumped LED the measurement is inherently incoherent. The method can easily be applied to multiport waveguide devices, such as couplers or power splitters, and is less sensitive to the occurrence of higher order modes than the Fabry-Perot method.

Conclusions: A new measurement technique has been presented to determine the losses of a wide variety of waveguide devices in III-V semiconductors. It is an alternative to the Fabry Perot method if multiport or multimode waveguide devices have to be measured. Coupling light into the waveguide is easily achieved by optical pumping of an integrated twinguide structure with a reproducibility better than 0·2 dB. The method is a first step towards integrated test structures for on-chip determination of the performance of optical devices.

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PLATINUM SILICIDE FUSION BONDING

Indexing terms: Silicon, Semiconductor devices and materials

Silicide direct bonding has been accomplished between silicon PtSi coated wafers and both PtSi coated and uncoated silicon wafers. Successful bonding occurred when the PtSi surface was rendered hydrophilic by a hot aqua regia selective etching and cleaning process. The PtSi provides bondable, relatively low resistance paths which provide electrical interconnections between circuit elements on the bonded pair of wafers.

Introduction: Silicon direct bonding was initially used in a 'bond and etch back' process to create high purity silicon on insulator material.[1] The direct bonding technique has recently been applied to silicon nitride coated wafers in addition to the earlier work on surfaces with silicon and SiO_2.[2] Researchers have used the technique to bond one patterned wafer to bulk substrates to create working electrical and mechanical devices.[3–4] Aligned silicon fusion bonding is an extension of these techniques that allows two prefabricated wafers to be fusion bonded with precise alignment to form a complete three dimensional microstructure.[5] A major area of application of aligned silicon fusion bonding involves formation of three dimensional integrated circuits. In this application it is essential to obtain electrical interconnections between the