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Low-Loss Two-Dimensional GaAs Epitaxial Waveguides at 10.6-μm Wavelength

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Abstract—**The successful fabrication of low-loss two-dimensional GaAs epitaxial waveguides by chemical etching for use in integrated optics at 10.6 μm is reported. Selective excitation of specific E_{pq}^y modes was observed by placing the prism at specific angles in the horizontal plane. Loss measurements showed no increase in attenuation for lower order E_{pq}^y modes (as compared to corresponding one-dimensional waveguide modes) when the guide width is 50 μm. As the guide width is reduced, there is a significant increase in attenuation as p increases.**

Two-dimensional waveguides etched for visible light and near infrared wavelength application frequently have high attenuation rates caused by scatterings due to surface irregularities [1]–[5]. Scattering loss should be substantially reduced at the long wavelength of 10.6 μm. We report here the successful experimental fabrication of two-dimensional GaAs waveguides by chemical etching. These waveguides are important to 10.6-μm integrated optics applications. For example, for electrooptical modulation, the RF electrode capacitance in the two-dimensional waveguide configuration, is less than the capacitance in the one-dimensional waveguide configuration; consequently, only small RF power ($p/\Delta f$ in the order of 0.01 W/MH) is needed to drive the two-dimensional modulator [6].

In our fabrication and evaluation process, one-dimensional waveguides were first fabricated by vapor phase epitaxial growth of GaAs thin film (using the group V hydride feed system and the HCl transport of Ga) on low resistivity n^+GaAs substrate. The thin film is typically 25 μm thick and the sample is typically $5 \times 2 \times 0.025$ cm in size. The attenuation rate of the one-dimensional waveguides is evaluated by exciting a specific guided wave mode with an input prism coupler and then coupling out the radiation in that mode some distance away by an output prism coupler. The slope of the line representing the output radiation intensity (with constant input CO_2 laser intensity) plotted on a logarithmic vertical scale as a function of the distance between two prisms plotted on a linear horizontal scale gives the attenuation of various modes. Typically, the attenuation rate of the TE_0 mode may vary from 1 db/cm to 3 db/cm for free carrier concentration $N_s \cong 10^{18}$ carriers per cubic centimeter in the n^+GaAs substrate and $N_f \cong 5 \times 10^{14}$ carriers per cubic centimeter in the GaAs film. For the sample VR5-422 the measured attenuation rate for the TE_0 mode is 4.1 db/cm while the attentuation rate for the TE_1 mode is 5 dB/cm.

Subsequently, the sample is first coated with SiO_2, 0.15 μm thick (using Emulsitone Silicafilm and subsequent heat treatment at 350°C) and then spin coated with AZ 1350 photoresist, about 0.5 μm thick. AZ 1350 is exposed in the usual manner through a suitable photo mask (made by conventional photolithography technique) to make an SiO_2 mask that will protect white areas in Fig. 1

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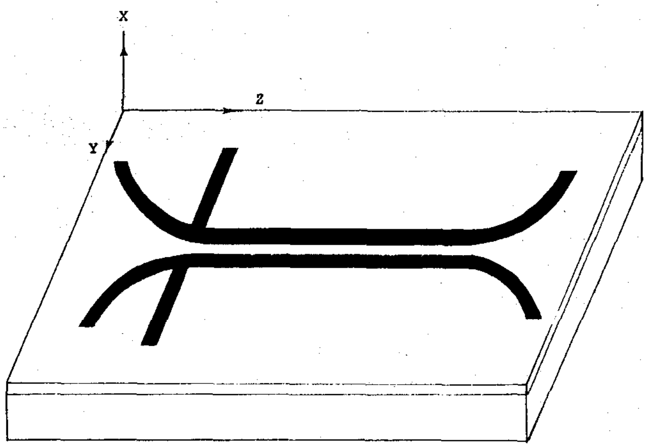

Fig. 1. Schematic diagram of an etched two-dimensional waveguide.

during chemical etching. Following that, the GaAs (dark area in Fig. 1) is etched about 25 μm deep by H_2SO_4:H_2O_2:H_2O (3:1:1) at 45°C for about 5 min; the SiO_2 mask is then removed by HF.

The resultant product schematically shown in Fig. 1 consists of a two-dimensional waveguide surrounded by deep etched grooves to isolate the waveguide from the surrounding mesa of GaAs. The two-dimensional waveguide has tapered transitions at both ends so that one-dimensional waveguide modes can be excited by the prism coupler and so that the taper will make a smooth transition from the one-dimensional waveguide modes to the two-dimensional waveguide modes. The surrounding mesa of GaAs is necessary to support the pressure of the prism coupler. The vertical deep groove cutting across the mesa shown in Fig. 1 is necessary to prevent radiation leaking from the input prism coupler to the output prism coupler through the surrounding mesa of GaAs. Fig. 2(a) shows a 500X magnification of a section of the etched waveguide where each large scale division corresponds to 2.2 μm in distance. Fig. 2(b) shows the profile of the waveguide monitored by Dektak. The surface irregularities caused by chemical etching are clearly much less than 1 μm.

We have been able to excite several E_{1q}^y and E_{2q}^y modes by setting the vertical angle of incident CO_2 beam with the input prism for $m = 0$ and $m = 1$ modes of one-dimensional waveguide. Modes having various values of q, the transverse mode order along the width of the two-dimensional waveguide, were excited by adjusting the horizontal angle between the input prism and the axis of the two-dimensional guide. When attenuation rates of the two-dimensional guide were evaluated by sliding the output prism coupler, we obtained 3.8 dB/cm for E_{1q}^y modes and 4.9 dB/cm for E_{2q}^y modes for small values of q.

This result demonstrated that no measurable increase in attenuation occurred for the two-dimensional waveguide modes E_{1q}^y and E_{2q}^y (with small q values) as compared to the TE_0 and TE_1 one-dimensional waveguide modes. The slight decrease in attenuation is probably caused by the fact that we have chosen a better section of the sample to make a two-dimensional waveguide. Similar results were obtained in sample VR5-424 where a 50-μm wide two-dimensional waveguide is fabricated. However, when a 25-μm-wide two-dimensional waveguide is fabricated on sample VR5-421 an increase of attenuation of 1 dB/cm occurred for the E_{1q}^y modes and an increase of attenuation of 6 dB/cm occurred for the E_{2q}^y modes.

In conclusion, we have demonstrated that conventional photolithography technique is adequate to yield low-loss two-dimensional GaAs waveguides for E_{1q}^y modes. The attenuation will increase significantly both when E_{pq}^y ($p \geqq 2$) modes are used and when the width of the waveguide is very narrow.

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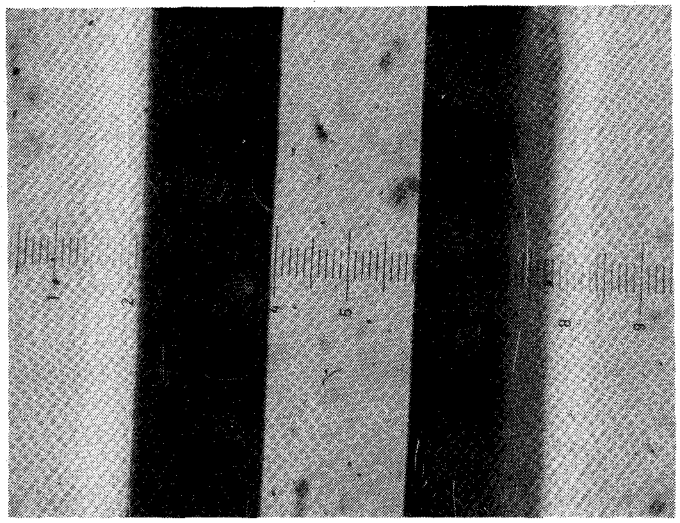
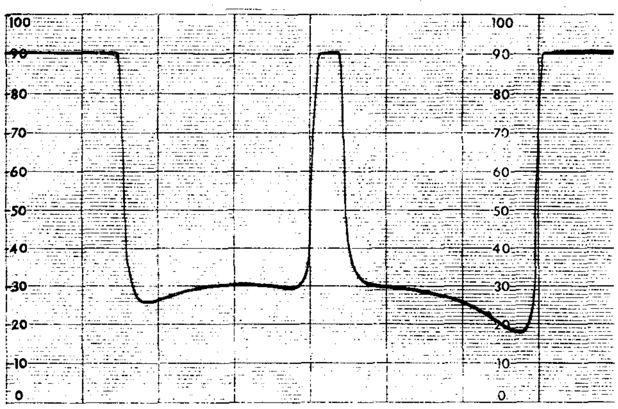


(a)



(b)

Fig. 2. (a) Photograph (500×) of a part of the 50-μm-wide two-dimensional waveguide fabricated on VR5-422. (b) Dektak trace showing profile of the 50-μm-wide two-dimensional waveguide. Horizontal magnification: 100; vertical full scale: 50 μm.

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