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Tertiarybutylarsine as a Substitute for AsH_3: Application to InGaAs/InP Photonic Integrated Circuits

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Photonic Integrated circuits (PIC's) in the InGaAsP/InP system require many different components such as lasers, couplers, waveguides, modulators etc., each requiring good optical and electrical properties. In the past most of these components were grown using AsH_3 and PH_3. For safety [1] and other reasons such as the ability to grow at lower temperatures [1], [2], [3], it is desirable to use substitute group V liquid alkyls such as tertiarybutylarsine (TBA) for AsH_3 or tertiarybutylphosphine for PH_3. Recently TBA has become available in a pure form and recent work has shown TBA capable of yielding device quality material in the GaAs system [4], [5], [6], [7]. as well as the InGaAs/InP system [8], [9], [10].

We have shown [8] that TBA-grown bulk layers of InGaAs and InGaAsP have nearly as good electrical and optical properties as AsH_3-grown layers. As a consequence conventional InGaAsP lasers at 1.3 µm were grown by TBA and were found to have properties as good as AsH_3-grown lasers. Continuing this work we present here investigations into other components of PIC circuits grown by using TBA as a substitute for AsH_3 ie: multi-quantum well (MQW) and strained layer MQW lasers, a 4-port directional coupler optical switch, and quantum-confined Stark Effect modulator structures. Data is also presented showing the difference in spatial uniformity between TBA-grown and AsH_3-grown material.

The results shown below were all obtained from wafers grown in either one of two 1" standard horizontal atmospheric MOVPE systems. Both systems were identical and employed a pressure balance run-vent manifold and incorporated dilution of the TMG and AsH_3/TBA sources. Details of growth have been described earlier [8], [11], [12].

Fig. 1a shows conventional SIPBH structure and Fig. 1b the active layer for the MQW laser. The histogram of the current threshold I_{th} for conventional InGaAsP/InP semi-insulating planar buried heterostructure SIPBH lasers lasing at 1.3 µm wavelength is shown in Fig. 2a As reported in Ref 8, these lasers had I_{th} as low as 11 mA and differential quantum efficiencies η_d as high as 21%/facet. These results along with low internal losses $\leq 21cm^{-1}$ make these lasers equivalent to AsH_3-grown lasers of this type. Fig. 2b shows the I_{th} histogram for 1.55 µm wavelength MQW lasers The MQW lasers had I_{th} as low as 18 mA and η_d as large as 22%/ facet. Again these values are comparable to those obtained earlier [13] using AsH_3.

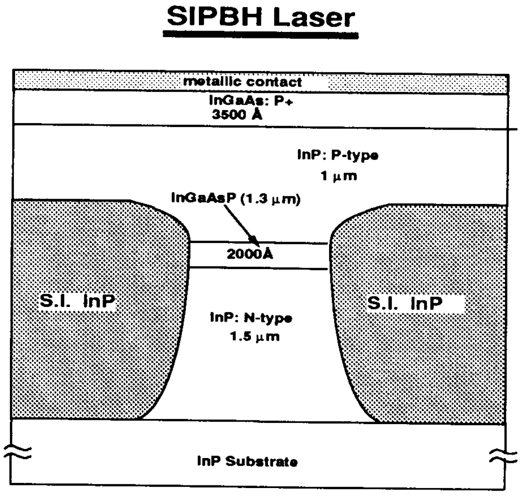

FIG. 1a. Conventional SIPBH structure.

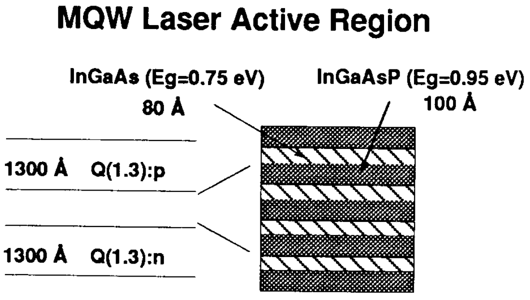

FIG. 1b. Active layer for MQW lasers. This replaces the 2000Å InGaAsP layer in Fig. 1a.

Strained layer SIPBH MQW lasers were also grown using TBA. The active layer structure is shown in Fig. 3 and replaces the InGaAsP 1.3 μm layer in Fig. 1a for the SIPBH laser. The In composition (x=0.77) of the quantum wells determines the strain (+1.53%) and it and the well thickness determine the lasing wavelength which was about 1.53 μm. This strain appears to be sufficient to realize any advantages for use in MQW lasers [14].The wells have to be kept thin in order to avoid exceeding the critical thickness. Fig. 4 shows the L-I curve from such a laser with a high reflective (HR) coating on the facet. I_{th} for this laser was 7.5 ma and η_d = 65% with a cw power out in excess of 20 mW. The laser had very low internal losses and by coating both facets it was possible to reduce I_{th} to 2.2 ma where η_d = 5.2% as seen in Fig. 5. This low I_{th} value represents a current density of 440 A/cm^2 and is slightly lower than the lowest value reported for MQW lasers at 1.5 μm wavelength [15]. It should be noted that these results were obtained in a growth system converted over to exclusive use of TBA and only afterwards were these type lasers grown in another system using AsH_3. As expected from earlier results, there was no significant difference between the TBA and AsH_3-grown lasers.

Using TBA, a PIC which included a 4-port directional coupler optical switch was grown as shown in Fig. 6. The directional coupler optical switch part was a zero-gap 4-port 3 dB coupler with the coupling region 300 μm long and 5μm wide. The PIC had two input waveguides and two output waveguides—2.5 μm wide ribs of 300Å thick InGaAsP (λ=1.3 μm)loading a 2700Å core InGaAsP (λ=1.3 μm) layer, all surrounded by semi-insulating InP—feeding the coupler(see Fig. 6 and inset Fig. 7). The total length of the device was 3 mm long. By injecting a bias current into the regions adjacent to the coupler, it was possible to

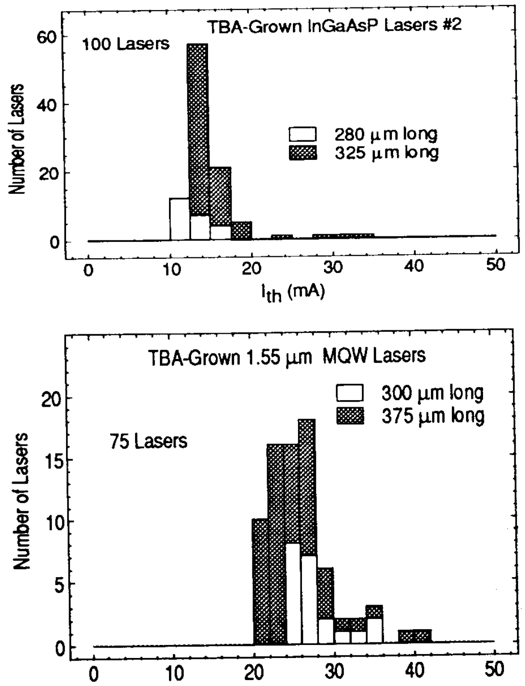

FIG. 2 I_{th} histograms of a) conventional and b) MQW lasers grown by TBA.

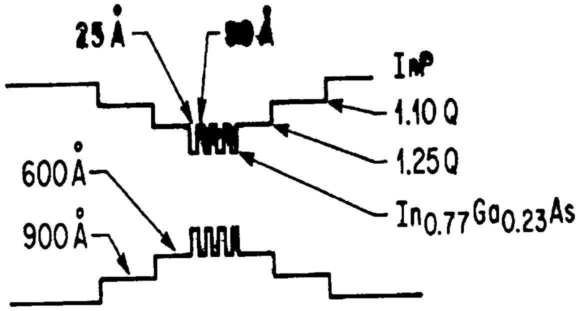

FIG. 3. Active layer structure for the strained layer MQW laser.

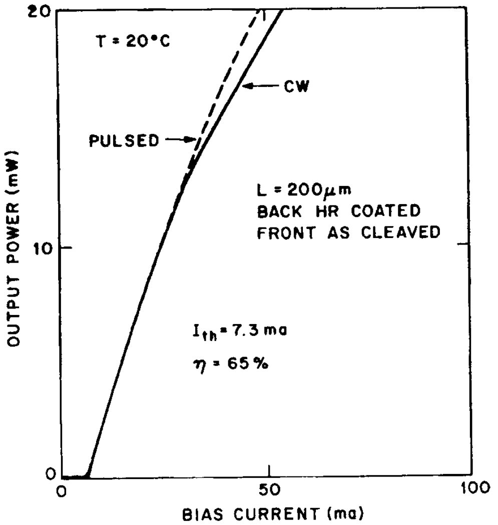

FIG. 4. L-I curve for a laser which has one high reflectivity mirror and one cleaved facet.

shift the coupling of an incoming wave (at 1.53 μm) into either of the two output ports as seen in Fig. 7. 3 dB coupling occurred at a bias of 43 mA with only 3% loss. At 200 mA bias, the switch had an extinction ratio of better than 6.6 dB with an excess loss of only 1.6 dB coming from free carrier absorption. These results are comparable to an earlier AsH_3-grown directional coupler optical switch.

A 20 cycle p-i-n InP/InGaAs 90Å/90Å MQW modulator structure was grown using TBA. This structure is typical of the quantum-confined Stark Effect modulators which might be used in PIC's. The I-V curves show good reverse characteristics having 10μA leakage at -18V. Fig. 8 shows the absorption spectrum as a function of the reverse bias. Even at -10V where the absorption edge has red-shifted 70 nm, the excitonic nature of the absorption is still preserved. Earlier work on AsH_3-grown modulators [16] has shown that these results are necessary in order to obtain good modulation and the present TBA-grown modulator appear identical to the earlier AsH_3-grown one.

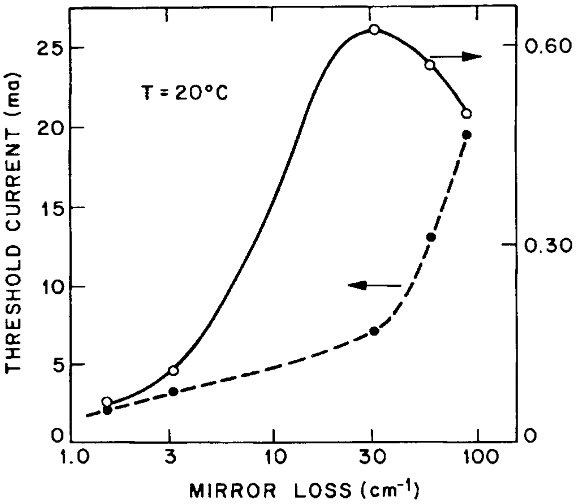

FIG. 5. Ith and η_d vrs mirror losses. The data points with mirror loses above 60 cm^{-1} were from uncoated lasers.

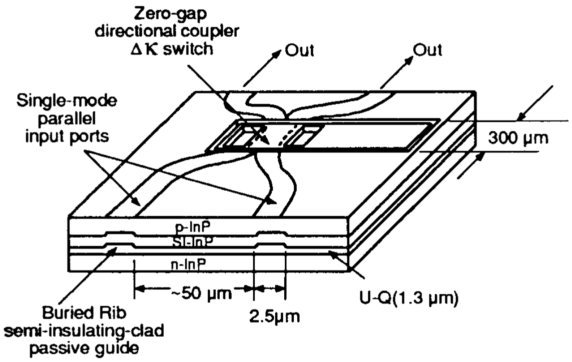

FIG. 6 Optical Coupler PIC. The loaded rib guides are shown approximately; details are shown in Fig 7 (inset).

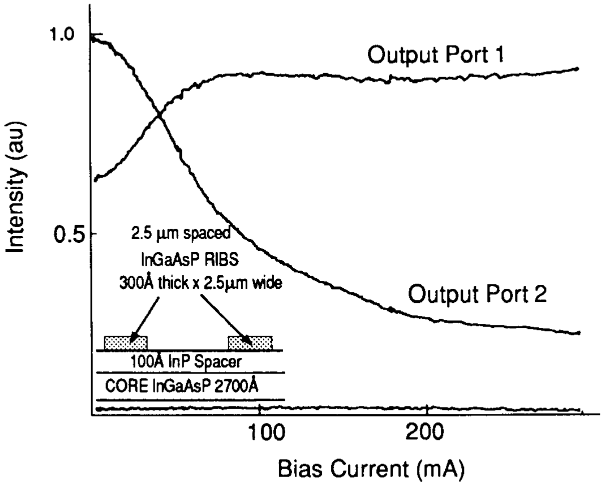

FIG. 7. Output from both ports as a function of coupler bias current. Inset shows the loaded waveguides in the region outside of the optical switch.

The spatial uniformity of TBA and AsH_3-grown InGaAsP (l=1.3μm) has been investigated and is shown in the plots in Fig. 9. Two wafers were grown successively one with AsH_3 and the other with TBA and are shown with their PL wavelengths and intensities for different positions on the wafers. It appears that the uniformity of the TBA-grown wafer is not quite as good as the one grown using AsH_3; similar differences were observed with wafers from earlier runs in the other 1" system. It should be pointed out that the growth conditions(ie: flow rates, temperature, V/III ratio's etc)

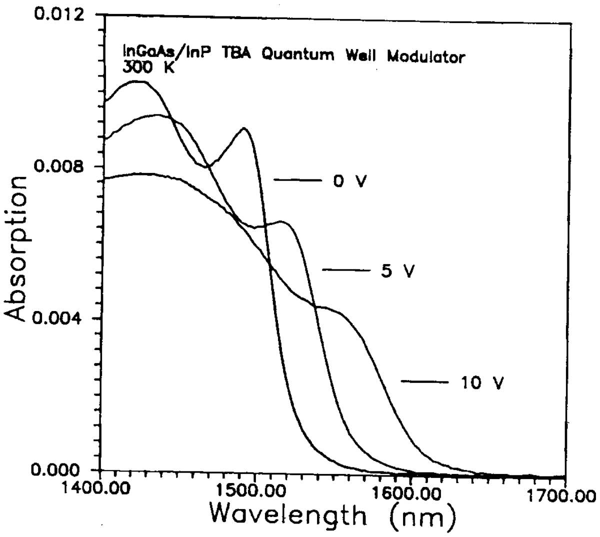

FIG. 8. Quantum Well Modulator absorption curve as a function of reverse bias.

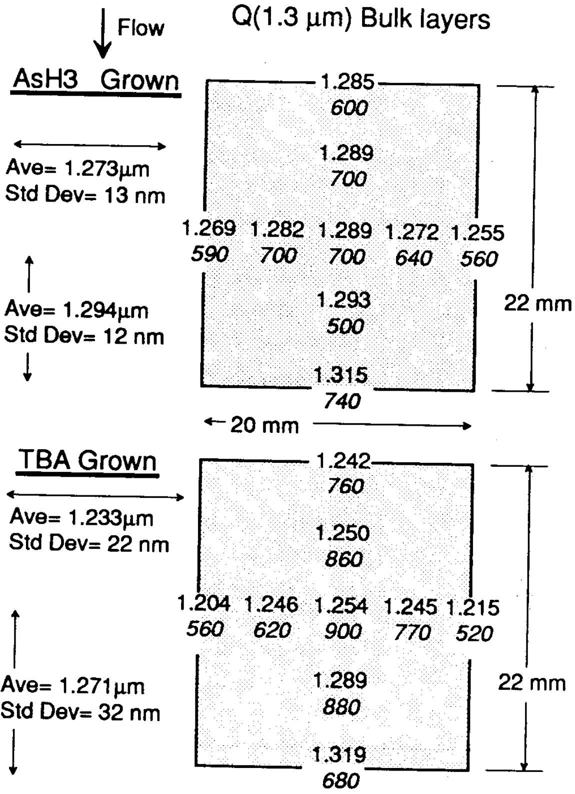

FIG. 9. PL wavelength in µm (regular type) and intensity in a.u. (in italics) over 2 wafers grown successively, one using AsH_3 and the other TBA.

were not optimized for the TBA. On the contrary, the values used for TBA growth in all the present work were the unmodified AsH_3 ones. It is anticipated that when the growth conditions for TBA are optimized, spatial uniformity should approach that of AsH_3.

From the results of this work it appears that lasers, waveguides and optical switches suitable for PIC's can be grown by TBA without compromising on performance. If PH_3 could be similarly replaced by TBP, then combined with TBA, the toxic hydride gases used for PIC production might be eliminated. This would make III/V material growth much safer and as a result should advance PIC development.

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