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# Asymmetric Twin-Waveguide 1.55-μm DFB Lasers for an Optical Beam Forming Network

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***Abstract*—An asymmetric twin-waveguide 1.55-μm DFB laser integrated with a passive waveguide crossing was fabricated for the optical beam forming network. A DFB laser with a side-mode suppression ratio of >45 dB and a waveguide crossing with a 16 dB cross-talk suppression ratio were obtained.**

***Keywords—DFB laser, waveguide crossing, asymmetric twin-waveguide***

## I. INTRODUCTION

With the rapid development of photonic systems, realizing low cost, multifunctional, high performance, chip-scale photonic integrated circuits (PICs) is a necessity. To realize PICs with low loss passive waveguides, integrated semiconductor laser on a silicon-on-insulator (SOI) platform and QWI technology have been demonstrated experimentally [1,2]. Another effective solution is to employ asymmetric twin-waveguide (ATG) technology [3], which does not need complex wafer growth processes. For compact and complex PICs, waveguide crossings are required for optical routing [4,5]. In this paper, an ATG 1.55-μm DFB laser integrated with a passive waveguide crossing was designed and fabricated for use in an optical beam forming network (OBFN). By using an exponential taper at the end of the DFB laser, the simulation shows that 89% power can be coupled from the upper active waveguide to the lower passive waveguide. With an elliptical parabolic taper waveguide crossing, a 40 dB cross-talk suppression can be achieved theoretically, although the measured cross-talk suppression is only 16 dB. The side-mode suppression ratios (SMSR) measured from the DFB side and through the waveguide crossing side are both larger than 45 dB.

## II. DEVICE MODELING, FABRICATION AND RESULTS

The generic ATG epitaxial structure was grown on a semi-insulating InP substrate, as shown in Fig. 1(a). Waveguide 1 is the lower passive waveguide, consisting of three periods of 1.1Q InGaAsP and InP stacks, which has low absorption at 1.55-μm wavelength. Waveguide 2 is the active waveguide and includes five AlGaInAs quantum well (QW) layers, and its refractive index is higher than that of waveguide 1 so most of the light would be confined in waveguide 2. A highly *n*-doped InP separation layer is sandwiched between waveguide 1 and waveguide 2, which also acts as a *n*-contact layer. Our proposed design of ATG 1.55-μm DFB laser integrated with a passive waveguide crossing is shown in Fig. 1(b). An exponential taper at the end of the sidewall grating DFB is 300 μm long and its width is tapered from 2.5 μm to 0.5 μm. A lower exponential taper of the same length, with its width changing from 6 μm to 2.5 μm, is connected to the lower passive waveguide. These taper structures are used to couple light from the 600-μm-long DFB section to the lower 2.5-μm-wide passive waveguide. The width of the grating ridge waveguide is 2.5 μm, with a grating recess depth of 0.6 μm and grating period of 244 nm. Simulation shows that 89% power can be coupled to the lower passive waveguide, as shown in Fig. 1(d). Light then passes through the elliptical parabolic taper waveguide crossing, then the light should propagate straight through the waveguide crossing. The radii of the short and long axes of the elliptical parabolic are 2 μm and 6 μm respectively. Figure 1(c) shows the simulated cross-talk suppression ratio for this waveguide crossing is around 40 dB. This device structure was realized by using a 3-step dry etch processes with a $Cl_2/CH_4/H_2/Ar$ gas mixture. First, the *p*-contact and top cladding layers were etched to form the grating and taper structures. Then, protecting the grating section and its two side areas, the structure was etched

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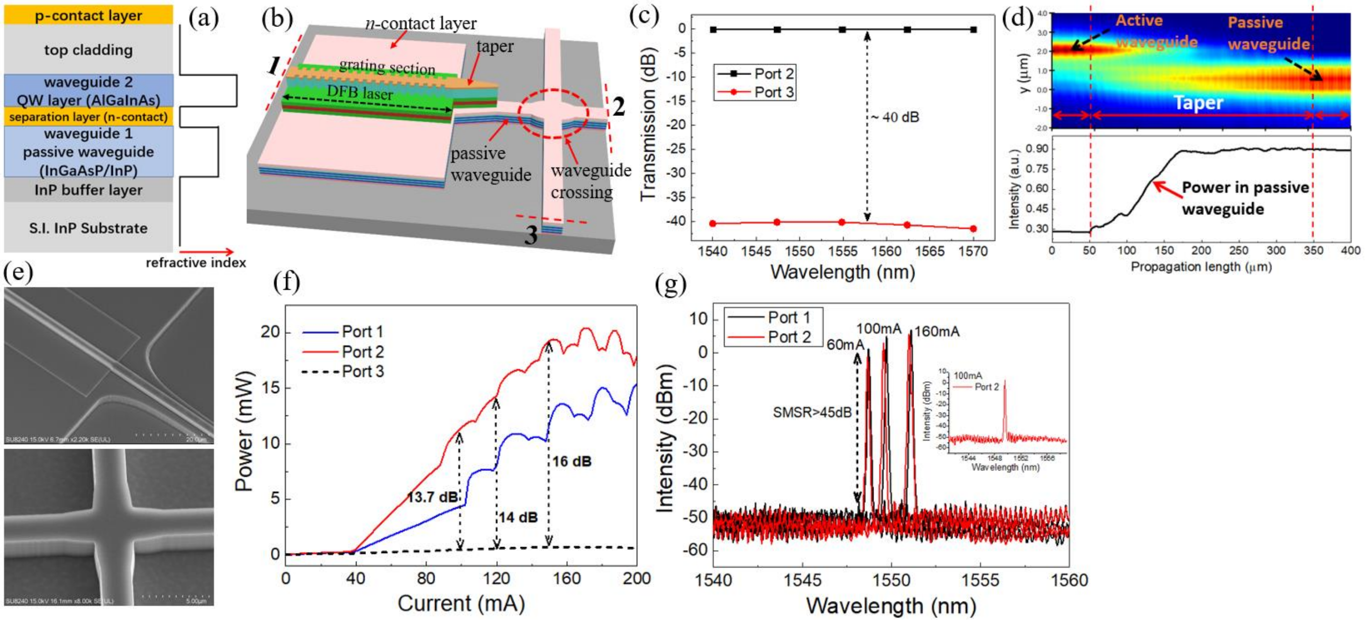

Fig. 1. (a) Generic ATG structure and its waveguiding index profile. (b) 3D view of ATG DFB laser integrated with a passive waveguide crossing. (c) The simulated light transmission in waveguide crossing. (d) Simulation of light propagation through the DFB active waveguide to the lower passive waveguide. (e) SEM images of the fabricated DFB grating, taper and waveguide crossing. (f) The measured output power from output port 1, port 2 and port 3. (g) The measured optical spectra from output port1 and port 2.

down to the *n*-contact separation layer. Last, after defining the *n*-contact area, the structure was etched through the separation layer and waveguide 1, down into InP buffer layer to create passive waveguides with a height of about 2.88 μm. Fig. 1(e) shows SEM images of the fabricated DFB grating, taper and passive waveguide crossing after the 3-step dry etch process. The devices was passivated, the *p*- and *n*-contact window opened, and metal deposition and annealing processes were applied to finish the fabrication. The devices were mounted epilayer up on copper heat sinks and measured under CW conditions at 20 °C after cleaving with both facets left uncoated.

In Fig. 1(b), port 1, port 2 and port 3 represent the output ports at the DFB side, waveguide crossing straight through side and crossing side respectively. The *p*-contact metal also caps the taper to pump the waveguide and reduce absorption loss in the taper section. Optical output powers from port 1, port 2 and port 3 were measured. The DFB threshold current is 38 mA, as shown in Fig. 1(f). The output power from port 2 can reach 20 mW at a DFB current of 170 mA. Due to the reflections from the grating coupler, taper and the uncoated facets, there are ripples or kinks in the *L-I* curves. Because of device heating, the phase of these reflections varies with the bias current. The reflection at port 1 should be larger than that from the tip of the taper, and more power will be transmitted in the port 2 direction, which accounts for the output power from port 2 being higher than that of port 1. The measured cross-talk suppression ratios of the waveguide crossing are 13.7 dB, 14 dB, and 16 dB at currents of 100 mA, 120 mA and 150 mA respectively. The measured cross-talk suppression is lower than the simulated result of 40 dB, and is limited by limitations of the fabrication process. The optical spectra from port 1 and port 2 were measured, while the output power from port 3 was too low to be measured. As seen from Fig. 1(g), the lasing wavelength positions from port 1 and port 2 are almost identical under the same currents of 60 mA, 100 mA and 160 mA, and the SMSRs are larger than 45 dB.

## III. CONCLUSION

In summary, an asymmetric twin-waveguide 1.55-μm DFB laser for an optical beam forming network was designed and fabricated. With proper design of the taper and waveguide crossing, a high coupling efficiency between the DFB laser section and lower passive waveguide can be achieved. A 16 dB cross-talk suppression at the waveguide crossing was obtained. Stable single mode operation with SMSRs larger than 45 dB can be realized.

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