(by a factor of $\pi/2$) and the power requirement more than doubles (by a factor of $\pi^2/4$), because the effective interaction length of the device is shortened due to the softened edges of the interaction region. This is a small price to pay for a tremendous improvement in channel isolation.

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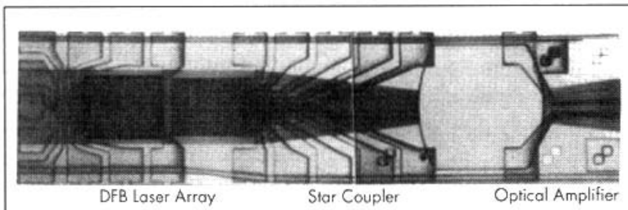
Monolithically Integrated 21-Wavelength DFB Laser Array with a Star Coupler and Optical Amplifiers

By Chung-en Zah and T. P. Lee, Bellcore, Red Bank, N. J.

We have reported previously multi-wavelength distributive feedback DFB laser arrays with as many as 20 wavelengths on a single chip fabricated by the use of strained-layer InGaAs/InGaAsP multi-quantum wells.[1] A wavelength span as large as 131 nm in the 1.5 μm wavelength region, a 3 dB modulation bandwidth as high as 16 GHz, and a linewidth as small as 180 kHz have been obtained. More recently, we have demonstrated monolithic integration of the laser array with a star coupler and optical amplifiers on the same chip to simplify fiber pigtailing. These devices have potential application for high density wavelength divisive multiplexing WDM systems, as well as for optical networks using wavelength routing.

Traditionally, the increased transmission bandwidth has been accomplished by time-division-multiplexing through



A micrograph of the top view of the monolithically integrated 21-wavelength DFB laser array with a star coupler and optical amplifiers.

the increase in the transmission speed. This is because the cost in transmission per bit per km of fiber has been decreasing continuously up to a speed of 2.5 Gbit/sec. As a result, the transmission capacity has been increasing at a rate about doubling every year from 1980 through 1988. Recently, commercial systems at rates of 1.2 and 1.7 Gbit/sec have been installed, and 2.5 Gbit/sec systems are planned for new installations. Although systems with even higher rates at 10 Gbit/sec have been demonstrated in the laboratories, commercial systems probably will not be available in the near future due to the unavailability of high speed electronics.

Because of the broad optical bandwidth (30 THz) available in the low-loss transmission window of the optical fiber, it is desirable to exploit the fiber bandwidth by wavelength division multiplexing (WDM) to overcome the electronic limitations, thus to further increase the transmission capacity. For example, early WDM transmission experiments at 10, 16, and 100 wavelength channels with the aggregated capacity of 20, 32, and 62 Gbit/sec,[2-4] respectively, were reported in 1985, 1988, and 1990. In the last two years, there were two major breakthroughs that make the WDM even more attractive. They are (1) the Er-doped fiber amplifiers (EDFAs), and (2) strained layer multiple quantum well laser diodes (SL-MQW-LDs). The EDFA eliminates the need of electronic regenerators, whereas the SL-MQW-LDs have very low threshold currents and large gain spectral width that permit multiple wavelength laser arrays to be fabricated on a single wafer. Furthermore, the EDFA has sufficient bandwidth to amplify many wavelength channels simultaneously; thus, it is cost effective in conjunction with WDM systems.

Distributed feedback laser arrays are attractive as multi-wavelength light sources for wavelength division multiplexed systems because a single TE cooler can be used to keep the relative wavelength spacing constant that facilitates a simple wavelength control and stabilization. By taking advantage of the wide gain width of the strained layer multiple quantum wells, we have recently fabricated multi-wavelength DFB laser arrays with as many as 20 wavelength channels in one array.[1] The channel spacing ranged from 3-7 nm, which can allow four to eight channels within the band of the Er-doped fiber amplifiers.

To make the DFB laser diode array a practical device, it is desirable to combine the multiwavelength output into a single-mode fiber pigtail. Recently, we have investigated monolithic integration of a multi-wavelength DFB laser diode array with a star coupler and an optical amplifier on one chip. After amplification, the combined signals in all wavelengths in the output waveguides of the star coupler can then be coupled into a single-mode fiber pigtail. The top view of a finished integrated laser array chip is shown in the figure. The 21-wavelength DFB laser array is connected to the star coupler through passive waveguides. Quantum well optical amplifiers were inbeded in two output waveguides near the center of the star coupler, and the remaining output waveguides are passive. The star coupler is formed by radially spacing the input and output waveguides with an angular increment of 0.6° on a 750 μm radius circle centered at the middle of the input and output waveguides. The active layer of the DFB lasers and the optical amplifiers consists of six compressive-strained $In_{0.7}Ga_{0.3}As$ wells. The gratings of different periods are generated by e-beam lithography.

Preliminary results show that the cw lasing wavelengths spans from 1512-1578 nm for 18 channels with threshold currents varying from 14-55 mA. The remaining three lasers have much higher thresholds. The channel spacing is 3.7 nm with a standard deviation of 0.38 nm. The side mode suppression ratio is typically better than 35 dB.

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Monolithic InP Grating-Based Wavelength Division Multiplexing Components

By J.B.D.Soole and A.Scherer, Bellcore, Red Bank, N.J.

The past year saw breakthroughs in a new component technology that promises to provide wavelength-specific devices for future wavelength division multiplexed (WDM) networks that have a high degree of wavelength control and a low manufacturing cost. To date, one of the greatest challenges facing implementation of proposed WDM networks is the practical realization of low-cost wavelength-specific opto-electronic components (lasers, detectors, etc.) that possess and maintain the wavelength accuracy needed for effective network operation. While many components are available or under development, there is no technology that provides these devices with the required wavelength accuracy, tolerance, and stability at low enough cost to make many of the networks commercially viable.

The new component technology uses a single-chip semiconductor wavelength multiplexer/demultiplexer integrated with different active elements to form a wide range of compatible wavelength-specific components.

The heart of the mux/dmux is a planar waveguide grating spectrometer into which a diffraction grating and stripe waveguides have been etched.[1,2] When a multi-wavelength signal is fed into an input stripe guide, it enters the body of the device and is dispersed by an etched diffraction grating; the wavelength-demultiplexed signals then exit the device via output stripe guides. Wavelength multiplexing is achieved by operating the device in reverse. Because wavelength selection relies on the device geometry, highly accurate specification of the wavelengths is possible.

The basic InP grating mux/dmux was reported in 1991; 1992 saw its integration with active elements to form WDM sources and receivers.

WDM detector arrays were formed by integrating waveguide p-i-n photodetectors with the output waveguides. Devices with both 42 and 92 channels were reported.[3,4] Channel separation was 4 nm and 1 nm, respectively, with 2 nm and 0.6 nm channel passbands. The detector arrays operated in the 1.5 μm fiber band and employed highly efficient (90%) waveguide photodetectors.

A 16-wavelength WDM laser, called the "MAGIC" (Multi-stripe Array Grating Integrated Cavity) laser, was also reported.[5] This has active gain elements integrated with the grating-based cavity. The planar guide body and the pumped stripes form the laser cavity, while the grating provides the wavelength selective intra-cavity element. By injection pumping one output stripe and different "second" stripes, lasing was obtained from the single output at different wavelengths. Like the dmux and detector array, the laser operated at wavelengths precisely determined by the device geometry.

The basic trio of WDM devices—source, filter, receiver—has now been demonstrated using the integrated grating technology. Their development and combination is expected. The great potential of the semiconductor grating-based technology, which arises from its ability to set the wavelengths accurately and the fact that fabrication is readily scalable to large-volume manufacture, assures that it will be actively pursued in the years to come.

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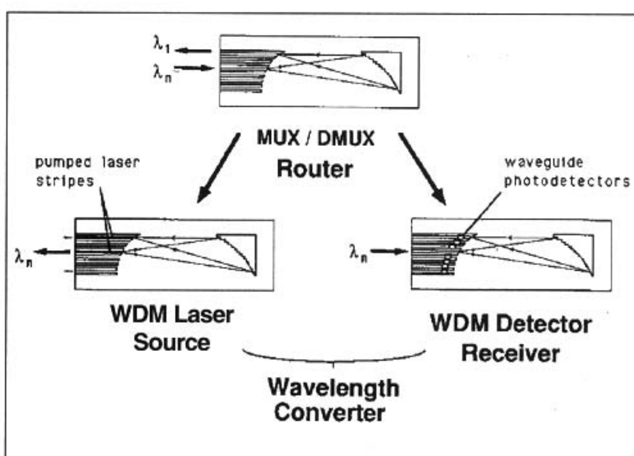

WDM components based on the InP grating mux/dmux. The combination of detector and laser yields an "electronic island" or node capable of intelligent wavelength conversion or translation.