Photonic Integrated Circuits with Wavelength Tunable Lasers

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ABSTRACT

Efforts to develop monolithic tunable lasers required the integration of several different waveguide elements, such as gain, phase modulator, and grating mirror sections. With this suite of components, more complex photonic ICs became possible.

In the 1980's coherent communication was widely investigated to increase receiver sensitivity and repeater spacing in optical fiber systems. It was also seen as a means of expanding WDM approaches because optical filters would not be so critical. This early coherent work drove early photonic integration efforts because of the phase stability such integration brings; it also drove work on tunable lasers for use both in local oscillators, which could be tuned across many channels in a single receiver, and also for use in flexible transmitters.

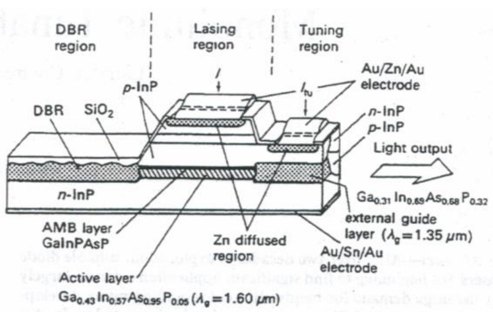


Fig. 1. Early tunable DBR laser[1].

Some of the earliest efforts to make single-chip tunable lasers resulted in technologies to integrate a variety of active and passive waveguide components that have enabled many of the photonic integrated circuits becoming technologically important today. Because of the interest in fiber optic communication systems, these were mainly based upon the InGaAsP/InP materials system, so that will be the focus of this paper. Seminal examples include work on tunable DBR structures from Prof. Suematsu's group illustrated in Fig. 1 [1] as well as some developments in coupled cavities by reactive dry etching technology from the author's group [2].

By the end of the 1980's photonic integration in these materials had been explored to the point where complete coherent receivers were attempted on a single chip as illustrated by the work of Koch and Koren [3] in Fig. 2. However, with the advent of the Er-doped fiber amplifier (EDFA), the desperate need to stretch the reach between repeaters in WDM systems waned, as all channels could now be amplified in an analog way without the need for optical demux/receivers; multichannel electronic amplification; mux/optical transmitters—so-called O/E/O.

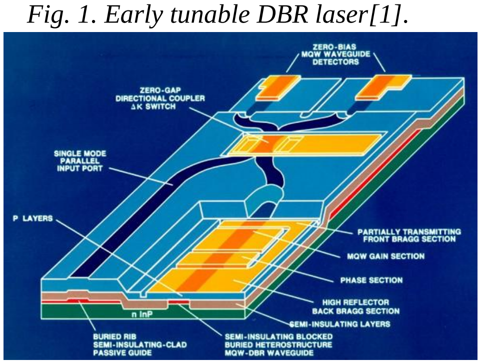


Fig. 2.Integrated heterodyne receiver[3].

Nevertheless, the desire to have widely-tunable lasers for dense WDM remained; a single laser that could be tuned to any channel across the entire C or L-band, perhaps 200 channels, was still a dream. Initially, it was considered just as a universal spare if a DFB laser should fail; however later (in the 2000s), once reliability and cost were competitive, it became the dense WDM source of choice. In fact, many applications besides fiber optic communications listed such a device as desirable. So, the exploration of such components continued throughout the 1990s, and with this exploration, the development of many new photonic IC elements continued. For example, grating-assisted vertical couplers, Y-branch couplers, sampled-grating DBRs, super-structure DBRs, and MMI couplers were perfected during this time [4].

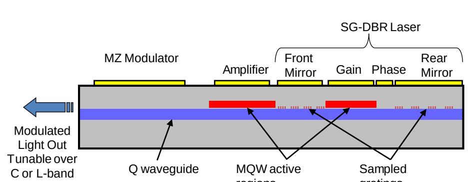
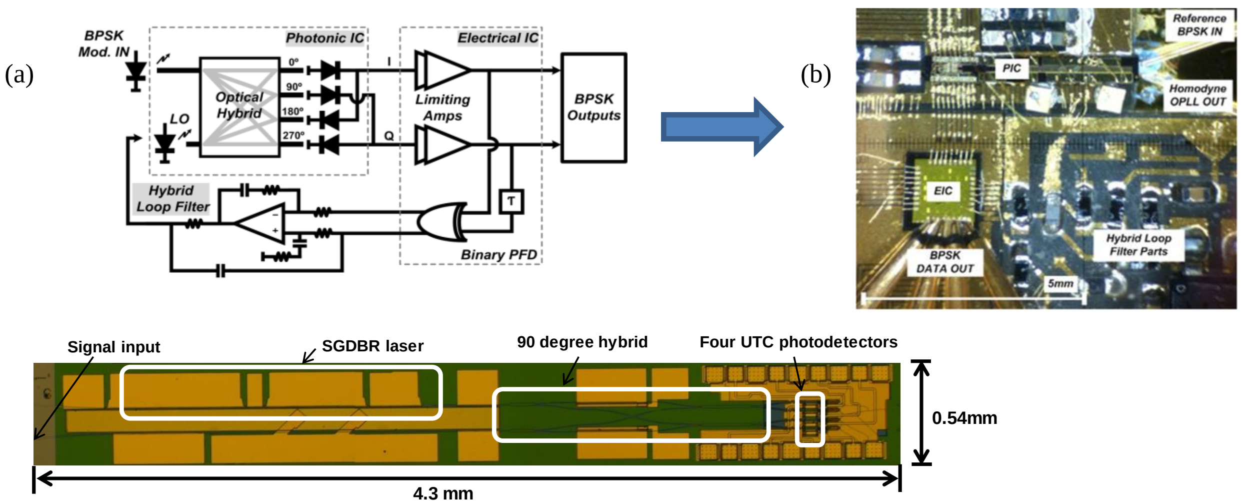


Fig. 3. SGDBR + SOA + MZM [5].

Figure 3 shows the SGDBR laser integrated with an SOA and a Mach-Zehnder modulator (MZM) [5]. This was first developed in the author's group with heavy influence from Agility Communications, a company started by former students of UCSB that continued to closely collaborate. Following the acquisition by JDSU, this basic structure has become a very popular small PIC, because of its small size and large capability. It can be tuned over 40 nm, with over 20 mW of fiber-coupled output—leveled by the SOA, the MZM can operate up to and above 25 Gb/s with low drive voltage and tailorable chirp.

In recent years, more complex PICs have been investigated for many applications, such as optical switching (including wavelength conversion)[6], free-space beam sweeping [7], and coherent communication [8,9] —all depending upon widely-tunable lasers for their functionality. Figure 4 illustrates an integrated Optical Phase Locked Loop (OPLL) circuit that contains a PIC and closely integrated Costa's-loop electronic feedback circuit, which can function either as a coherent receiver or as a frequency synthesizer [10], depending upon the nature of the feedback circuit. The receiver is shown. It provided error-free BPSK operation up to 40 Gb/s without careful temperature (~3°C) or vibration control on a ~cm^2 area ceramic substrate. As shown in Fig. 4(c), the PIC itself contains a widely-tunable local oscillator, a 90° hybrid, and 4-UTC photodiodes, so one might call it alone an integrated coherent receiver; but of course, its I, Q, I' and Q' outputs are only descrambled when phase-locked to the incoming carrier of the signal. [This can also be done with an ADC/DSP circuit, but this would be much more expensive, bulky, power hungry, and with FEC, high latency.]



(c)

Fig. 4. (a) OPLL schematic; (b) OPLL photo; (c) expanded PIC photo [9].

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