Chapter 1
Introduction

1-1 Preface

Telecommunication lasers have evolved substantially since the introduction of the early AlGaAs-based semiconductor lasers in the late 1970s suitable for transmitting multimode light at 850 nm. Focusing on DWDM applications (in the 1550 nm window), distributed feedback lasers (DFBs) are today's incumbent. However, with the advent of tunable laser technologies, whose most immediate benefit is the ability to reduce inventory levels, a new breed of lasers based on some variant of the distributed Bragg reflector laser (DBRs), external cavity lasers (ECLs) or vertical cavity surface emitting lasers (VCSELs) structure represents a more viable alternative to DFB lasers. Tunable lasers offer many compelling advantages over fixed wavelength solutions in optical networks in that they simplify planning, reduce inventories, allow dynamic wavelength provisioning, and simplify network control software. Furthermore, tunable lasers are being featured in optical network development efforts spanning nearly all application segments, from access/enterprise through metropolitan and long haul networks, which have lead to a variety of desired specifications and approaches.

1-2 Types of Tunable Lasers

Tunable lasers offer an extra degree of freedom in DWDM systems, which facilitate fast optical switching, flexible reconfiguration of networks, and reduced inventories. There are several types of tunable lasers: array of distributed feedback lasers (DFBs), distributed Bragg reflector lasers (DBRs), sampled-grating distributed Bragg reflector lasers (SG-DBRs), super structure grating distributed Bragg reflector lasers (SSG-DBRs), grating-assisted co-directional coupler laser with super structure grating Reflector lasers (GCSRs), external cavity lasers (ECLs), vertical cavity surface emitting lasers (VCSELs). We will introduce them simply below.

1-2-1 Array of Distributed Feedback Lasers (DFBs)

DFB lasers are the technology of choice for fixed wavelength DWDM transmitters. In DFB lasers, a grating is formed by etching a periodic corrugation into the waveguide active layer. The grating acts as a series of distributed tiny mirrors, on which the light bounces back and forth allowing only one mode to survive in the cavity. The operating wavelength of the laser is controlled by the period of the grating. A selectable array of DFB lasers is shown in Fig.1-1. DFB lasers are excited one at a time and each is manufactured with a slightly different grating pitch to offset their output wavelengths by about 3 or 4 nm. The chip is then thermally tuned by some 30-40 ^{0}C to access the wavelengths between the discrete values of the array elements. For a typical DFB the thermal tuning coefficient is in the order of 0.1 nm/°C. With N-DFB lasers, a wavelength range of up to about 4N nm can be accessed.

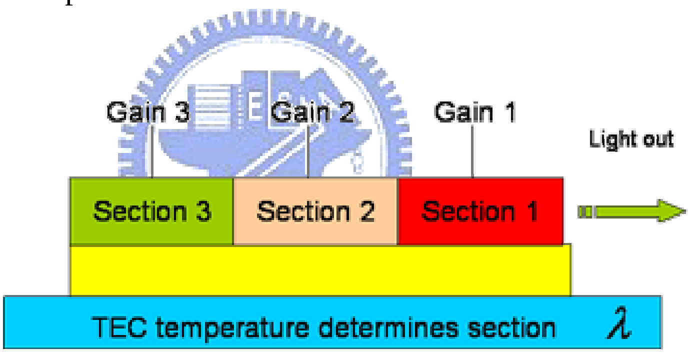


Fig. 1-1 The structure of selectable DFB array

1-2-2 Distributed Bragg Reflector Lasers (DBRs)

The conventional DBR laser used a distributed Bragg reflector as a tunable frequency selective element. The DBR laser shown in Fig. 1-2 is made up of a gain section, a phase section, and a grating section. The active section is used to produce the optical gain. A tuning is accomplished by injecting current into the DBR section, which changes the carrier density, thereby changing their refractive index. The phase section is used to align a cavity mode with the reflection peak, and thus do the fine-tuning.

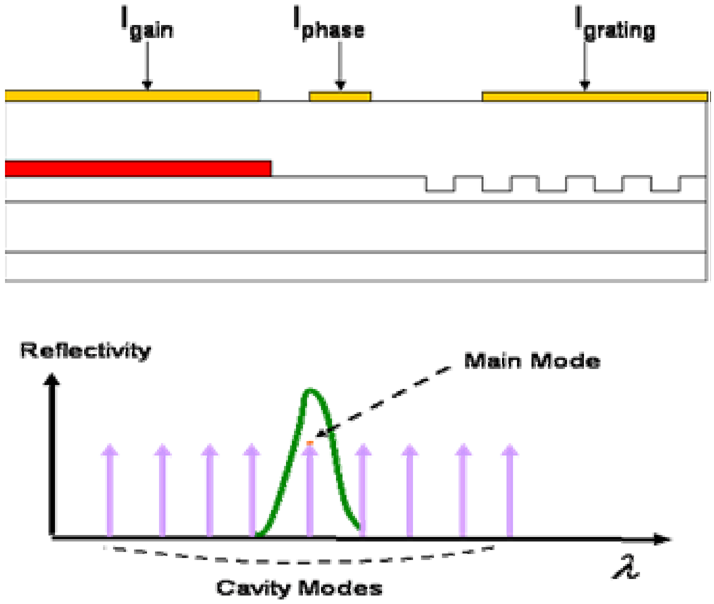
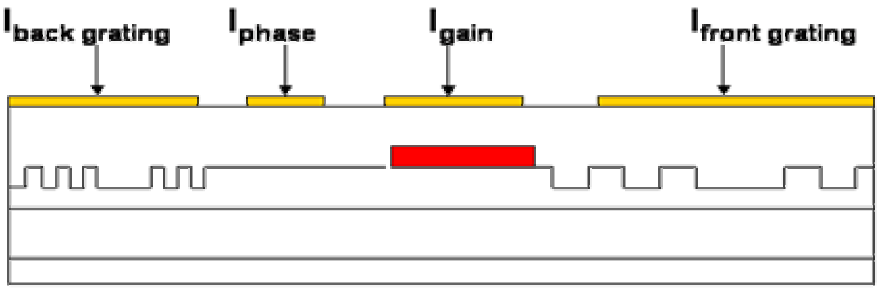


Fig. 1-2 The structure of conventional DBR laser and mode selection

1-2-3 Sampled-Grating DBR Lasers (SG-DBRs)

The SG-DBR laser shown in Fig. 1-3 is another variant of DBR laser whose main difference is the presence of a pair of grating mirrors at either end of the cavity. The SG-DBR laser consists of a gain section, a phase section, and two grating sections. The gratings are periodically sampled or blanked out, which results in a sequence of equally spaced short grating bursts. The bursts give the mirror a comb-like reflection spectrum with multiple equally spaced peaks. Just as in DBR, the gratings can be tuned by current injection. It can be proven that by differentially tuning the mirrors it is possible to achieve a wider tuning range than with a simple DBR.



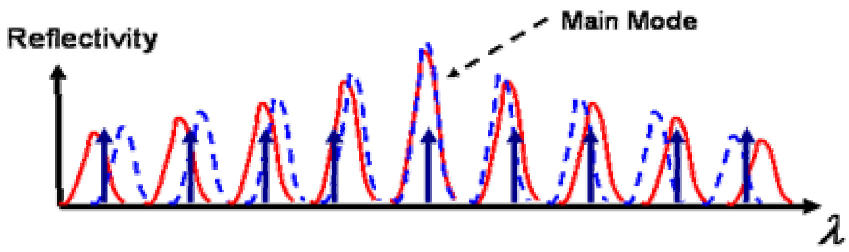


Fig. 1-3 The structure of SG-DBR laser and mode selection

1-2-4 Super Structure Grating DBR Lasers (SSG-DBRs)

The structure of SSG-DBR laser shown in Fig. 1-4 is similar to that of the SG-DBR laser. Their difference is the grating structure, which consists of a nearly linearly chirped grating, and result in the equalized comb-like reflection spectrum peaks. Therefore, the tuning range of the SSG-DBR laser is wider than that of the SG-DBR laser.

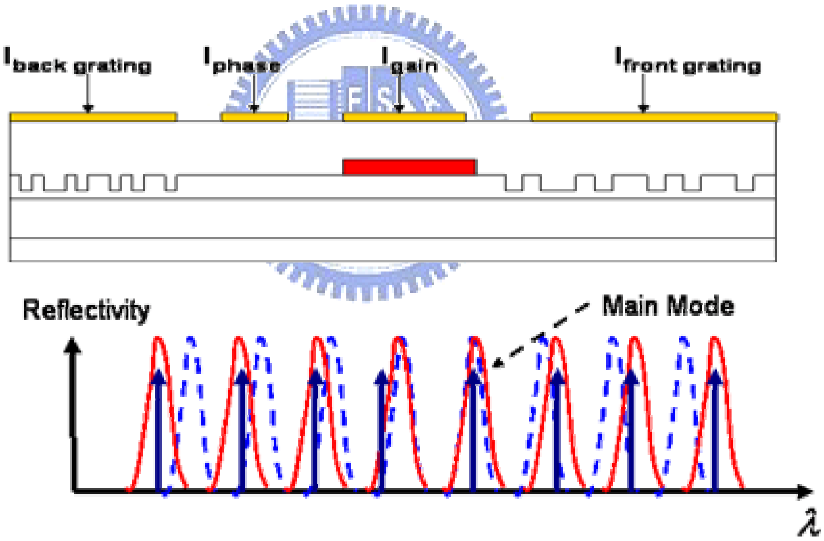


Fig. 1-4 The structure of SSG-DBR laser and mode selection

1-2-5 Grating-assisted Co-directional Coupler Lasers with Super Structure Grating Reflector (GCSRs)

The GCSR laser shown in Fig. 1-5 consists of a gain section, a coupler section, a phase section, and a reflector section. In the GCSR laser, the transmission peak through the grating assisted coupler is used to select the appropriate reflection peak for lasing. The coupler is thus used for coarse tuning, the reflector is used for intermediate tuning, and the phase section is used for fine-tuning of the laser so that any frequency within the tuning range can be reached.

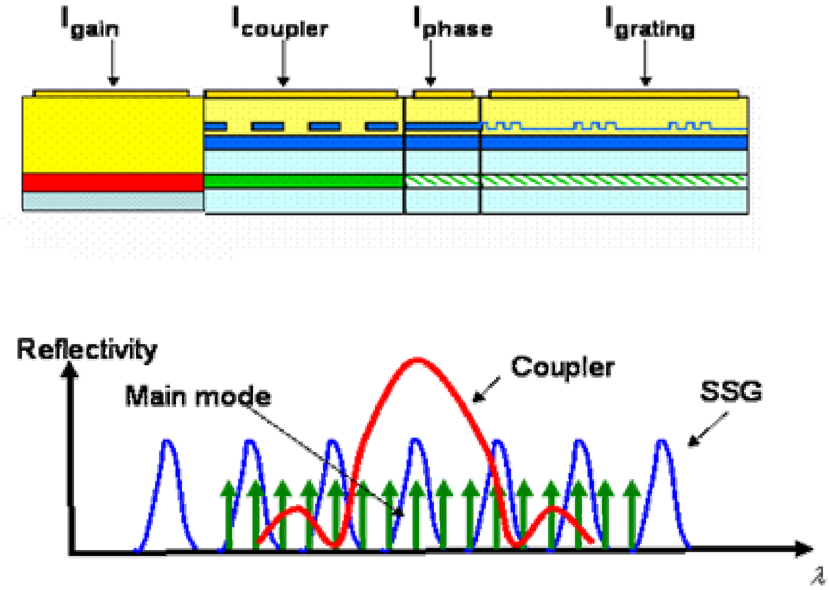


Fig. 1-5 The structure of GCSR laser and mode selection

1-2-6 External Cavity Lasers (ECLs)

The external cavity laser (ECL) shown in Fig. 1-6 uses a conventional laser chip and one or two mirrors, external to the chip, to reflect light back into the laser cavity. To tune the laser output, a wavelength–selective component, such as a grating or prism, is adjusted in a way that produces the desired wavelength. The external cavity is of a type known in the art as a Littman-Metcalf resonator, in which the zeroth-order output from a diffraction grating is used as the laser output and the first-order-diffracted light is retro-reflected by a cavity feedback mirror, which establishes one end of the resonator. The other end of the resonator is the output surface of a Fabry-Perot resonator that constitutes the diode-laser gain element. Wavelength selectivity is achieved by choice of the angle of the diffracted return beam, as determined by position of the feedback mirror. ECLs are used in optical test and measurement equipment. Besides, ECLs are attractive for some applications because they are capable of very high output powers and extremely narrow spectral widths over a broad range of wavelengths.

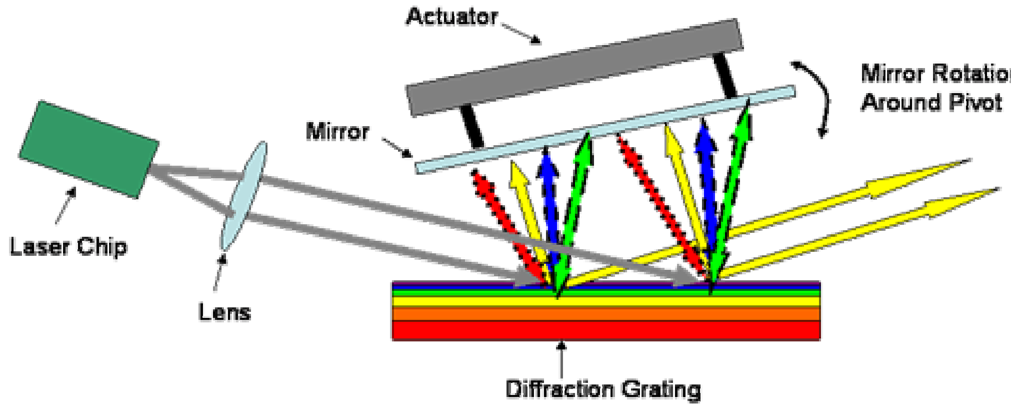


Fig 1-6 The structure of external cavity laser

1-2-7 Vertical Cavity Surface Emitting Lasers (VCSELs)

The alternative to edge-emitting lasers is the vertical cavity surface emitting laser (VCSEL) shown in Fig. 1-7. Rather than incorporating the resonator mirrors at the edges of the device, the mirrors in a VCSEL are located on the top and bottom of the semiconductor material. This setup causes the light to resonate vertically in the laser chip, so that laser light is emitted through the top of the device, rather than through the side. As a result, The VCSEL emits much more nearly circular beams than edge-emitting lasers do. What's more, the beams do not diverge as rapidly. These benefits enable the VCSEL to be coupled to optical fibers more efficiently. In tuning the VCSEL, the technique used is based on mechanical modification of the laser cavity using micro-electromechanical systems (MEMS) technology. This approach enables VCSEL / MEMS devices to achieve a relatively wide tuning range.

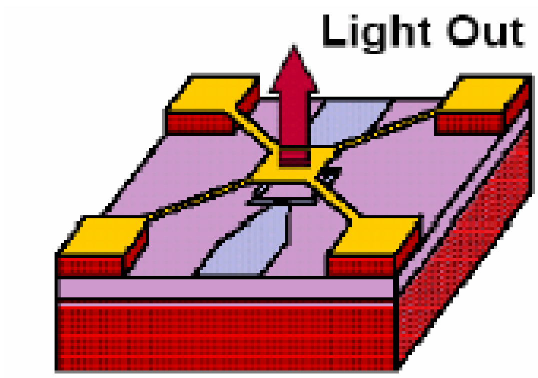


Fig. 1-7 The structure of MEMS VESEL

1-3 Comparisons of Tunable Lasers

From the above discussions, it should now be apparent that there are numerous possibilities to achieve wavelength tunable laser sources. A summary of several key performances for the various tunable laser technologies is shown in Table 1-1.

	Tuning Method	Max. Tuning Range	Power	Switching Time	Network Applications
DFB	Temperature	5 nm	13 dBm	---	LAN
DBR	Current	8 nm	3 dBm	0.5 ns	LAN
SG-DBR	Current	57 nm	8 dBm	4 ns	LAN, MAN
SSG-DBR	Current	83 nm	0 dBm	2 ns	LAN, MAN
GCSR	Current	114 nm	3 dBm	2 ns	MAN
VCSEL	MEMS	35 nm	6 dBm	1 ms	MAN
ECL	Mechanical	40 nm	13 dBm	10 ms	MAN, Long Haul System

Table 1-1 Comparisons of characteristics for various tunable lasers

Further, for each kind of network application, these widely tunable lasers must fulfill stringent requirements which could change from one application to the next. These are summarized in Table 1-2. These requirements can be divided into four groups. The four groups are devoted to longitudinal single-mode operation criteria, tunable operation criteria, transmission system criteria, and industrial mass production, respectively. For example, the side-mode suppression ratio (SMSR) higher than 40 dB over the whole tuning range, the high number of accessible channels, and the reliability of all these channels belong to the first, second, and third groups, respectively. These requirements are useful to make a comparison between all the tunable structures proposed and to select the one which exhibits a better tradeoff between performances and fabrication and operating simplicity.

Main Specific Requirements
--The first group--
1.High Side Mode Suppression Ratio (>40dB) 2.High output power coupled into the fiber 3.Switching time in the range of few ten nanoseconds
--The second group--
1.Stability of the wavelength channels 2.High number of accessible wavelength (regular spacing)
--The third group--
1.Low output power variation over the whole tuning range (<3dB) 2.High reliability of the device
--The fourth group--
1.Simplicity of fabrication compatible with low cost mass production 2.Simplicity of operation and characterization (low number of tuning currents)

Table 1-2 Main specific requirements which must be satisfied by tunable lasers

1-4 The Organization of Thesis

In chapter 2, the theory and design of sampled grating distributed Bragg reflector lasers (SG-DBRs) are described. Firstly, we simulate the spectra of sampled gratings and analyze the characteristics of sampled gratings. Secondly, the operation principles of SG-DBRs and Vernier effect are introduced. Thirdly, we derive the oscillation conditions and design sampled gratings. Finally, we simulate the characteristics of oscillation conditions such as oscillation wavelengths, the threshold gain and spectra of sampled gratings with current injection in the sampled grating sections.

In chapter 3, the static tuning properties are studied in terms of the threshold current, the oscillation wavelengths, output optical powers, side mode suppression ratio (SMSR), and linewidth. In addition, we demonstrate a widely tunable laser that accesses 40 ITU channels with 100-GHz spacing and switches in less than 200 ns.

In chapter 4, we reviews contents of my thesis and make a summary.