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Optical design of a miniature semi-integrated tunable laser on a Silicon Optical Bench

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Abstract

There is an increasing demand for tunable lasers in telecommunications networks for test equipment, optical components and other applications. In DWDM systems, multiple data streams propagate concurrently on a single mode fiber. DWDM networks are based on a DFB lasers operating at a wavelength defined by ITU wavelength grid. Statistical variations associated with the manufacture of DFB laser results in yield losses. Continuously tunable external lasers are developed to overcome the limitations of DFB lasers. Various laser tuning mechanisms are being explored to provide external cavity tunable lasers to provide a stable single mode output.

The packaged tunable laser source (TLS) for DWDM network also need to include several optical elements for isolation and data modulation like collimator, focusing lens, fiber pigtail, a modulator and output fiber segment. In this publication, we propose a novel semi integrated miniature high frequency tunable laser design based on Silicon Optical Bench (SiOB) concept. One of the mirrors is a movable MEMS structure changing the optical path length. We propose micro optical design between laser diode and the MEMS mirror for efficient optical coupling and side mode suppression. We also present the compatibility between the optical coupling and MEMS actuation range. We present the coupling efficiency results over the tuning range. We also propose a method of monitoring the output power of the tunable laser using waveguide coupler structures which are integrated in the silicon wafer and method of packaging in a miniature package compatible to the industry standard form factor.

Keywords: Tunable Laser, MEMS, Silicon Optical Bench, Miniature Optical Packaging, DWDM transponders

1. Introduction:

Tunable lasers promise a flexible and cost-effective future for optical networking, providing redundancy for the fixed wavelength lasers in a DWDM (Dense Wavelength-Division Multiplexing) link. Tunable lasers offer a significant opportunity for cost reduction. Wavelength tuning will allow efficient bandwidth usage and the provision of new and adaptable customer services. Tunable lasers have been of research interest for few years.

The telecom optical applications require tunable lasers with capability for high speed modulation for dynamic networks and wavelength configurable optical modules in WDM (Wavelength Division Multiplexing) networks. Vast reduction in operational costs is predicted for such flexible fiber optic networks. However, the challenge for the package designers is to develop tunable laser with high-frequency modulation with the same performance specs as existing directly modulated DFB (Distributed Feed Back) lasers and in a form factor that can be incorporated in existing transceiver modules. As telecom manufacturers strive to reduce costs for their customers, a high level of integration within both the optical modules and associated electronics is in great demanded.

A laser's wavelength is determined by its optical cavity, or resonator. Fig. 1 gives a schematic of a generic tunable laser together with the relative spectra of the necessary filter and gain elements as well as the location of the various cavity modes that all must be properly aligned and translated to create a tunable, single-frequency laser. The output wavelength, λ, the cavity mode number, m, effective index of refraction seen by the cavity mode, n , and the effective cavity length L, are related by the relationship

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$$\lambda = 2.L.\ n(\lambda)/m$$

Following Ref [1], the relative wavelength change is directly proportional to the relative change in either the length, index or mode number

$$\Delta\lambda/\lambda = \Delta n/n + \Delta L/L - \Delta m/m$$

The mode selection filter, external mirror and phase-shifting elements can be combined to create a unique physical structure for the different kinds of tunable lasers. The most common gain medium is the Fabry-Perot laser chip without the reflection coating on end facets. The tunable lasers are strictly wavelength selectable continuous wave optical sources and they need to be integrated with external modulators for operation in telecom transceivers. Thus, there has been research to develop tunable modulating coherent wavelength source using external Optical modulator like Mach-Zehnder interferometer.

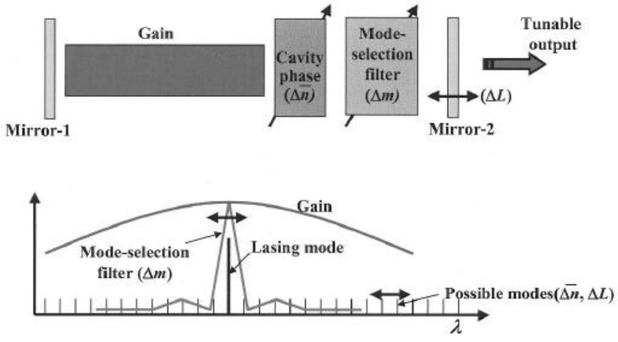

Fig. 1 Principle of Tunable laser [1]

2.0 Description of proposed tunable laser package

The present manuscript describes a single chip integration of an electro-optical modulator, MEMS tunable element and silicon optical bench for a small form factor TOSA module. The required devices and components for a Tunable modulating TOSA package are: III-V gain chip with sufficient broad band output, a MEMS actuated mirror to tune the wavelength of the gain chip, a coupling element between the gain chip and MEMS, an external modulator (preferably on Silicon for monolithic integration), an optional optical isolator close to the gain chip (which is required for high frequency optical TOSAs for long haul operations), a coupling element between the modulator and the gain chip, a waveguide tap and monitor photo diode for power adjustment, an optional on-chip optical amplifier for output power stabilization and an optical fiber for output. Such an embodiment needs to be mounted on a Thermo-Electrical Cooler (TEC) with a thermometer to monitor temperature and provide closed loop operation..

We describe a scheme to integrate the above components on a single wafer as shown schematically in Figures 2a and 2b, respectively for the cross-sectional view and top view. The proposal aims at achieving a complex assembly using accurate silicon micro machining to assemble devices in cavities made in silicon while maintaining the optical axis between different devices/components to a high accuracy. The wavelength tuning can be realized by various kinds of MEMS devices, such as electrostatic driven or thermal driven micro flat mirror, curved mirror, or grating. The coupling between optical components can be achieved by either discrete optics such as ball lens, collimators or tapered couplers. The MEMS tuning part can be integrated with the modulator by micromachining process or by packaging the individual devices. The MEMS grating, actuator, silicon optical modulator and the optical trenches are formed at the wafer level followed by solder and metallization structures on the top. The monitoring coupling is obtained by horizontal or vertical coupling waveguide tap. The process to integrate MEMS wafer with modulator wafer has been finalized and is submitted for patent process (ref 6). The accuracies of silicon micro-machining process has been tested by fabricating test structures and has been presented elsewhere (ref 7).

Fig 2 (a) describes the cross-sectional view of the TOSA assembly in one configuration using discrete ball lenses while fig 2 (b) describes the top view. The gain chip together with the MEMS mirror forms a tunable laser part. The output of the gain chip is coupled to the silicon optical modulator through another focusing lens. A tap waveguide is formed to couple part of the light to a monitor photo diode to achieve stable optical power output from the laser chip. Finally, the output of the modulator is coupled to a fiber either directly or through Semiconductor Optical Amplifier (figures 3 a and 3 b).

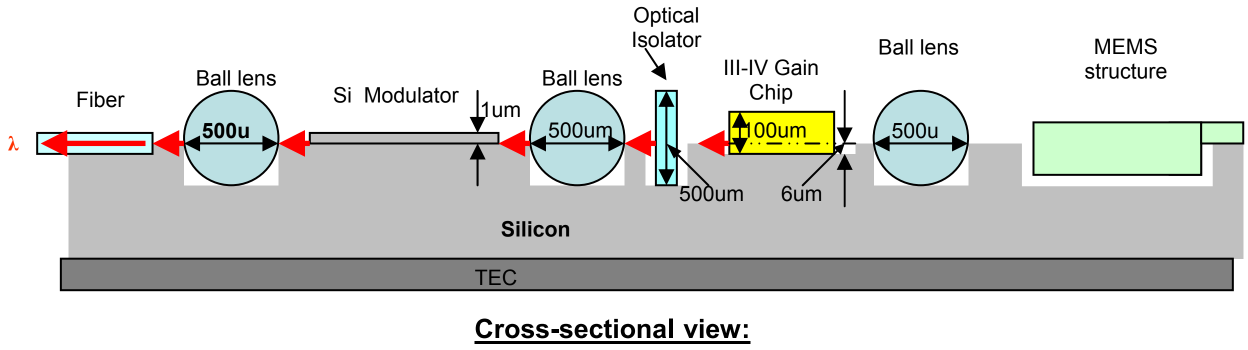

Fig. 2 a Cross sectional view of the integrated high speed tunable laser

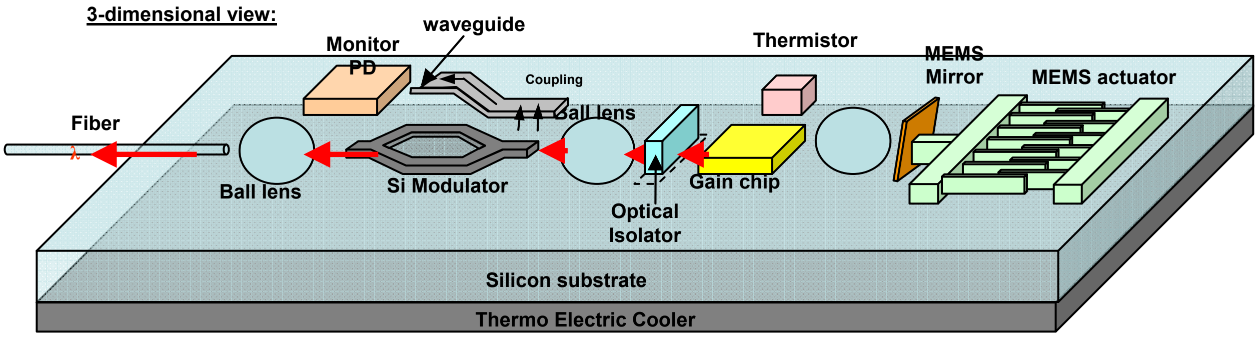

Fig. 2b Three dimensional view of integrated high speed tunable laser

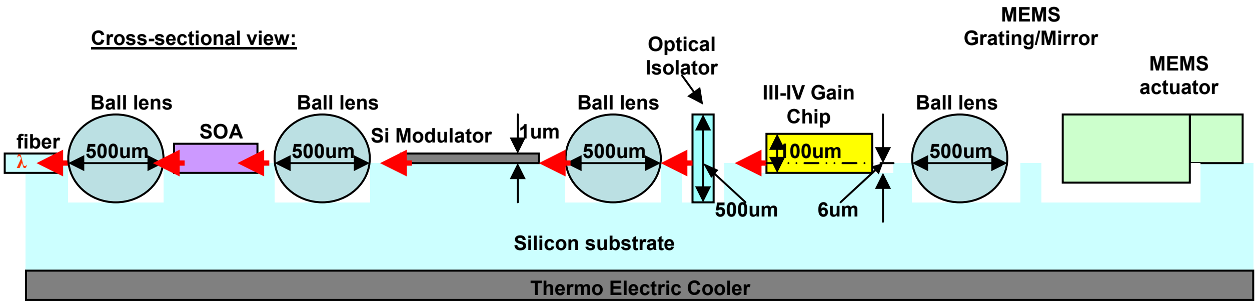

Fig 3 a: Cross-sectional view with semiconductor optical amplifier added to improve the output

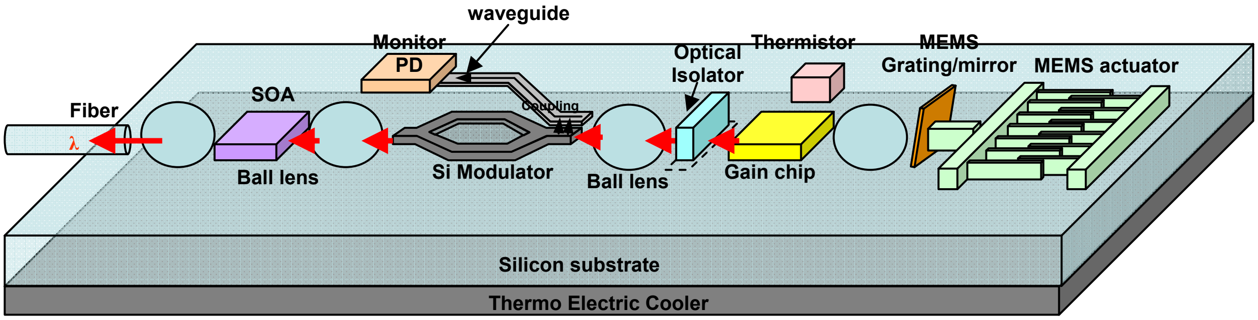

Fig 3 b: top view of the TOSA with Semiconductor Optical Amplifier

The sub assembly above needs to be maintained at a stable temperature for reliable operation in case of DWDM network operation. This is achieved by mounting the silicon substrate on a Themo Electric Cooler (TEC) and attaching a thermistor on the Silicon substrate to monitor the temperature and provide the feedback. An external Thermo Electric Cooler Controller maintains the required temperature.

The configuration above can be integrated with a laser diode driver electronics and optical modulator driver electronics to achieve further integration. The package also needs to be hermetic package according to the Telcordia reliability requirement for optical modules. A surface mount assembly on a Silicon Optical bench can be realized by patterning the edge of the silicon wafer with gold followed by solder and sealing with another silicon cap from the top.

3.0 Architecture description and design results

In the present manuscript, we describe the optical coupling design and MEMS actuation requirement calculations for the Tunable Laser. We studied two commercially available BK7 and Sapphire ball lenses. We considered ball lenses because they are easier to be placed in a V groove formed in a silicon wafer. The TLS-lens-MEMS configuration is unfolded by replacing the MEMS with a dummy aperture and the reflection scheme is replaced with a transmission scheme to enable optical simulation. The simulation focused on two main tasks: (i) the variation of coupling efficiency with MEMS actuation and (ii) the effect of lens dispersion on coupling efficiency at a given actuator location. It was found that with just a plane MEMS mirror and actuator without any optical wavelength dispersing components, it is possible to achieve Coarse WDM functionality using the method described above. The MEMS actuation is estimated to be about 40um and the wavelength range considered was from 1550 to 1580nm – however, the method is applicable for the entire C and L band with a proper spacing between the lens and the gain chip. The optical design schematic is shown in figure 4. The illumination map at the rear facet of gain chip after transmission is shown in figure 5. The results for the optical coupling efficiency with MEMS actuation are shown in figure 6 for both Sapphire and BK7 lenses of 500um diameter for a given lens location when the lens dispersion is considered. It can be seen that the amount of reflected energy varies due to the change of focal length of the lens and can be a factor to change the wavelength of emitted light. The second result refers to the dispersion of light for a fixed MEMS actuator location. This study is conducted to study the suitability of the architecture for wavelength discrimination. These results demonstrate that the proposed architecture can be used as a wavelength selection mechanism without any optical dispersing elements like diffraction gratings or prism.

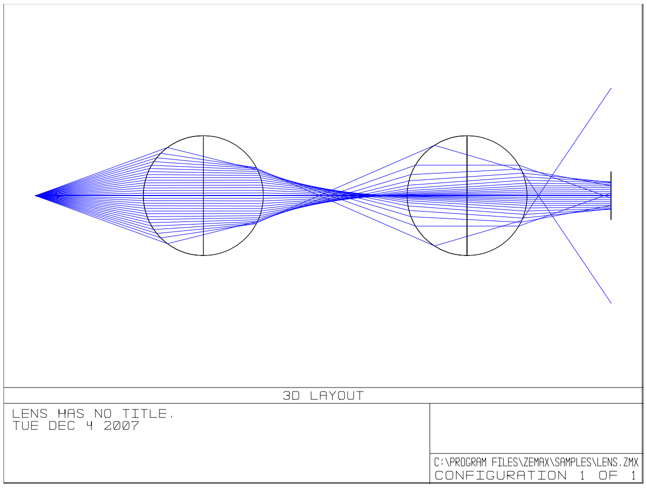

Figure 4: Schematic diagram for Optical design model.

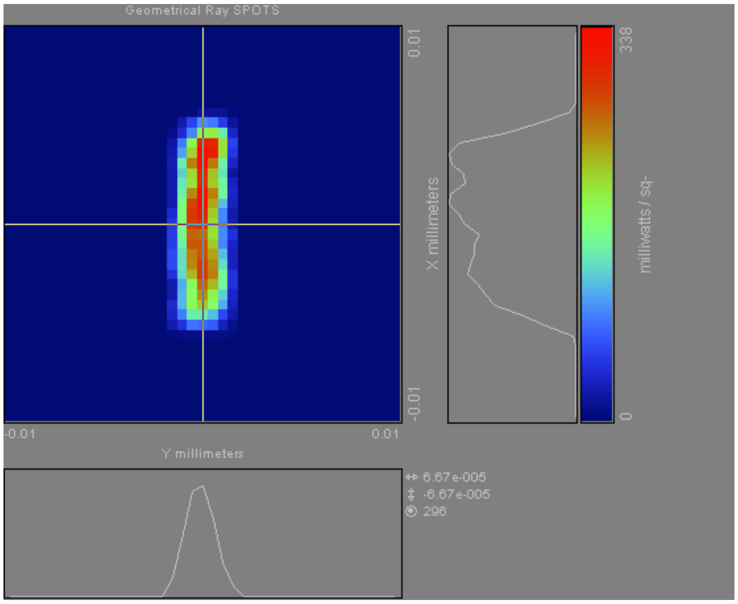

Figure 5: Beam profile through the lens at the gain chip

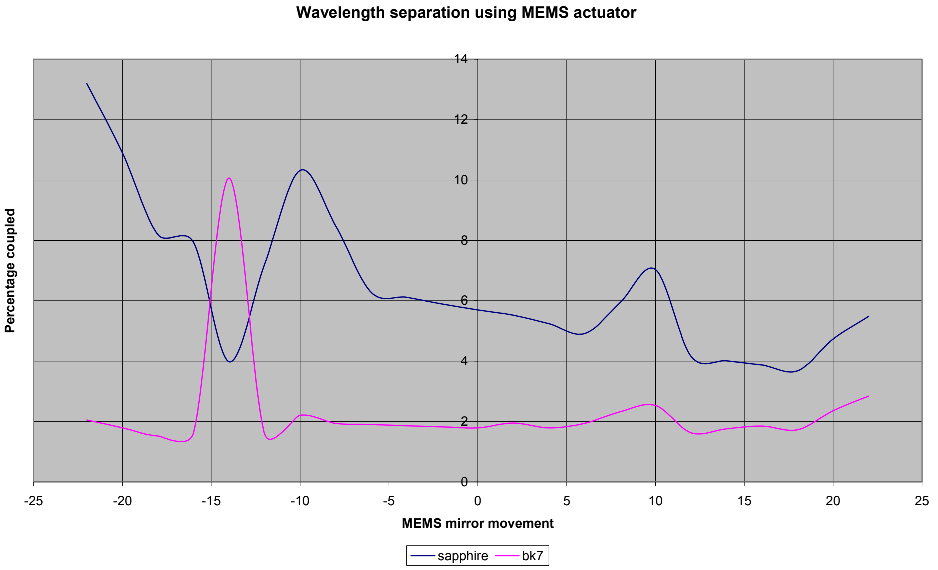

Figure 6: Optical coupling efficiency for a fixed wavelength with actuator movement

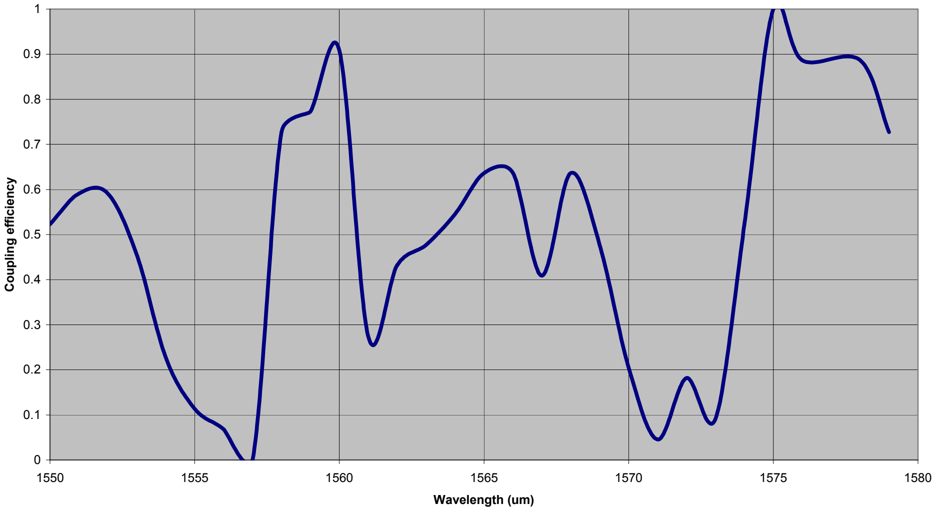

Figure 7: Optical coupling efficiency vs wavelength due to lens dispersion property

4.0 Summary:

A method of packaging a miniature high frequency tunable laser suitable for WDM networks is presented. The package is suitable for semi-automated assembly, amenable for wafer level processing of substrate. The wavelength tuning is accomplished through the wavelength dispersion of the coupling lenses and MEMS actuators. The design results are presented showing that the method can result in an uncooled CWDM tunable laser. Further work is in progress.

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