

## Integrated multi-wavelength lasers : a design study

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## **Integrated multi-wavelength lasers: a design study**

Jing Zhao, Xaveer Leijtens, Boudewijn Docter, Meint Smit  
COBRA Research Institute, Technische Universiteit Eindhoven, Postbus 513,  
5600 MB Eindhoven, The Netherlands. Email: J.Zhao@tue.nl

*Multi-wavelength lasers (MWLs) play an important role in wavelength division multiplexing networks, and also in photonic radar beam steering applications. In this paper we study different options for realizing such lasers, monolithically integrated with radio frequency (RF) modulators that can be modulated up to 40 GHz. Configurations of arrayed waveguide grating (AWG)-based MWLs integrated with Mach-Zehnder modulators are discussed. Depending on the application, they can have spatially separated modulated outputs or the modulated signals can be multiplexed onto a common output. A novel configuration, that exploits the reflection and transmission properties of on-chip reflectors is presented.*

### **I. Introduction**

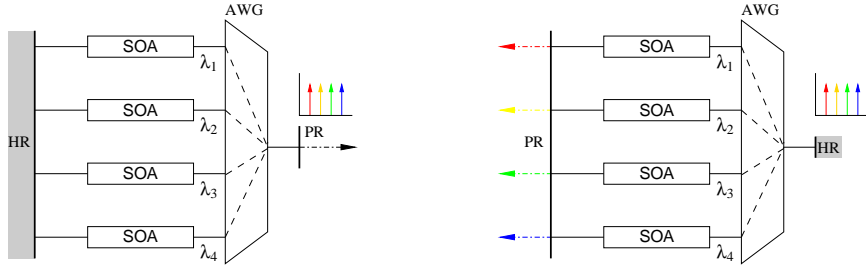
Multiwavelength laser sources have potential applications in instrument testing, sensing, and wavelength-division-multiplexing (WDM) networking systems. These multiple wavelength simultaneously emitting light sources are attractive as they provide an efficient and economical way to increase the transmission capability of WDM systems. Furthermore, there has been a growing interest in applying the multiwavelength scheme to reduce the complexity of the optical beam forming networks for optically controlled phased array smart antennas [1].

Currently, in WDM networking systems, the existing optical transmitters and receivers are mostly based on a number of fixed wavelength lasers combined with external modulators or in some cases using directly modulated lasers. After light generation and modulation, the signals will be multiplexed or directly sent to the next element, where it may be amplified, switched or experience other processing. Separate lasers and dedicated modulators are used for each wavelength transmission channel. However, using the lasers and associated components for each wavelength channel is very costly and inefficient. A possible way to improve the multiwavelength transmitter system is by monolithically integrating the multiwavelength laser sources and electro-optic modulators on a single chip, which can dramatically reduce the size and cost [2].

Section II of this paper describes a conventional AWG-based multiwavelength laser scheme. In section III we detail the integration configurations of AWG lasers and Mach-Zehnder electro-optical modulators, both with multiplexed and with separate outputs.

### **II. Arrayed waveguide grating based multiwavelength laser**

By combining a series of Semiconductor Optical Amplifiers (SOAs) with an Arrayed-Waveguide Grating (AWG) in a Fabry-Pérot cavity, multiwavelength lasers can be realized. Using monolithic integration, these components have been fabricated on a single chip using an active/passive integration technology in indium phosphide (InP). An early example is given by Zirngibl [3]. Such an AWG based laser (AWGL) has a several of advantages over other multiwavelength lasers and tunable lasers. First, it has the ability to



**Figure 1:** A basic arrayed waveguide grating laser configuration. (left) with multiplexed laser outputs; (right) with separate laser outputs. Partial and high reflection facets are denoted by PR and HR, respectively.

deliver light at the available wavelengths simultaneously and efficiently into the same output waveguide. Second, it has a good long term wavelength stability due to the fact that the wavelength selection is done by a passive optical element. Third, it has a much less complex wavelength control mechanism compared to the more conventional multi-section tunable devices that rely on accurate control of tuning currents.

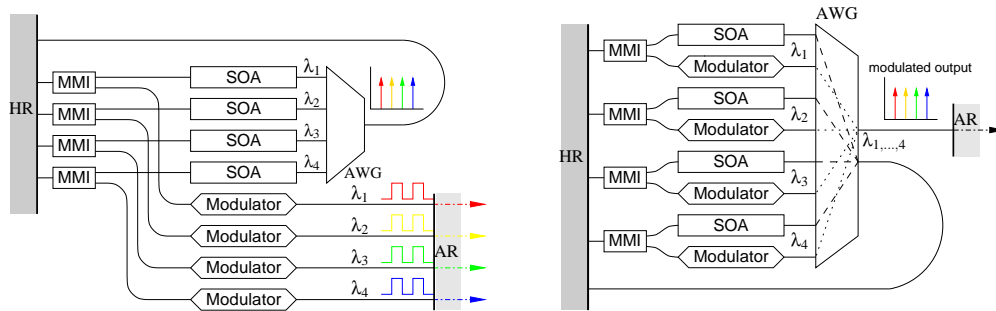
The basic AWGL configuration consists of an AWG (de)multiplexer with an array of SOAs connected to its demultiplexed ports and a common output waveguide connected to its multiplexed port [4]. Reflections at the common output facet and at the individual waveguide facets from the SOAs form the extended laser cavities. Figure 1 shows the basic schematic of such a laser with four wavelength channels, where the AWG is acting as an intra-cavity wavelength filter. The cavity loss is only minimum for the specific wavelength corresponding to the maximum of the AWG passband. In this way, each amplifier has a fixed lasing wavelength, determined by the filter characteristics of the AWG. In practice, one side of the chip is often high reflective (HR) coated to form good mirrors for the laser cavities, and the other side of the chip is partially reflective (PR) coated to enable outcoupling of the light. In this device, depending on whether multiplexed outputs or separate wavelength outputs are needed, the PR coating can be applied on the common output facet, while HR coating is applied on the individual facet side, Figure 1(left), or the other way around, Figure 1(right), respectively.

Based on this basic AWGL scheme, in combination with optical power splitters and on-chip (partial) reflectors, different configurations of AWGLs, possibly with integrated RF modulators can be designed, as will be shown in the next section.

### III. Multiwavelength lasers integrated with modulators

There are several options for realizing on-chip modulators in InP-based semiconductors. The two main choices for optical intensity modulation are electro-absorption modulators (EAMs), and Mach-Zehnder modulators (MZMs). Electro-absorption modulators have the advantage of small device size, but Mach-Zehnder modulators employing the electro-optical effects in InP-based materials, have the advantage of larger wavelength independence, high optical power handling, and zero chirp [5]. We decided to first investigate the use of MZMs in our MWL designs. The modulators will have 1 to 2 mm length traveling-wave phase-shifters in one or both of the interferometer arms.

For a high speed modulation, up to 40 GHz, the modulators have to be designed outside the laser cavity, to ensure the stability of laser and the modulation frequency and preclude

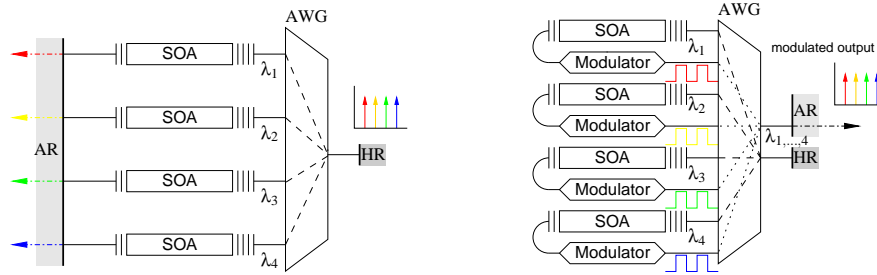


**Figure 2:** Configuration layout of (left) Cleaved-facet cavity MWL with modulators and with separate modulated outputs; (right) Cleaved-facet cavity MWL with modulators and with multiplexed common outputs

the large frequency chirp originating in the SOA. Conceptually, it is straightforward to tap a fraction of power from the laser cavity, and feed that light into a modulator. This is depicted schematically in Figure 2(left), which shows how  $1 \times 2$  multi-mode-interference (MMI) power splitters are included to tap out half of the light reflected from the individual facets of each laser cavity and that light is routed to the modulators, where the electrical RF signals are modulated onto the optical carriers. Then the different wavelengths of the light can be coupled out from the AR coated side of the chip. Alternatively, the outputs can be multiplexed by a second AWG that has passbands matching the AWG in the laser cavity.

A more elegant solution is shown in Figure 2(right), where the different wavelengths are combined by the same AWG that also provides the intra-cavity filtering. This ensures perfect passband alignment, and in addition, by passing the filter again, the sideband signals are further suppressed. The multiplexed laser light exits from a different output port of the AWG, where it can be routed to the AR-coated facet of the chip. The penalty is that a larger-sized AWG is needed with twice the number of channels at half the channel spacing.

Using the AWG as intra-cavity filter has the disadvantage that it creates a long lasing cavity possibly with extra unwanted reflections and losses. A promising alternative is to have a short Fabry-Pérot laser that is wavelength locked through filtered-feedback from an extra-cavity AWG filter [6]. For such an integrated laser, an on-chip reflector that allows part of the signal to be transmitted is required. Deeply etched DBR mirrors have been shown to be good on-chip reflectors [6], of which the reflectivity and transmission can be designed to match the requirements for the application. Figure 3(left) shows the layout of an AWGL that makes use of these deeply etched DBR mirrors. The wavelength selection is now done outside the laser cavity, by the feedback provided by the AWG. The main Fabry-Pérot laser cavity is formed by the SOA and the two deeply etched DBR mirrors located on either side of the SOA. A small fraction of the light is transmitted through the DBR mirror and will be filtered by the AWG and fed back into the laser cavity, thereby locking the laser to the wavelength determined by the feedback. Compared to the basic AWGL configuration, in this short cavity design, the undesired reflections and losses introduced by the AWG are outside the main laser cavity and their influence on the laser performance will be much reduced. Moreover, the laser cavity length can be precisely defined, because the DBR mirror can be positioned with lithographic precision, while the positions of a cleaved facet is difficult to control accurately. The accurate control of the laser cavity



**Figure 3:** Configuration layout of (left) MWL with deeply etched DBR laser cavities; (right) deeply etched DBR laser cavities MWL integrated with modulators and with multiplexed output.

length enables tight control over the mode spacing of the laser, that can be set to be a multiple of the AWG channel spacing.

In addition, the utilization of DBR mirrors also simplifies the integration of the laser with modulators. The fraction of the light that is transmitted through the DBR grating on the left hand side can be directly routed to the modulator. In this way the extra loss from the 3-dB splitter in the previous design can be avoided. After modulation, the signals can exit separately from an AR coated facet. Alternatively, they can be multiplexed with the same AWG, as is illustrated in Figure 3(right) and as discussed above.

#### IV. Conclusion and acknowledgement

Several ways of integrating multiwavelength lasers with modulators have been discussed. We presented a novel concept using deeply etched DBRs to make the integrated MWL and modulator system more stable and less complex.

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