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Overview of Multi-Wavelength Laser Generation Techniques

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Abstract:
Multi-wavelength laser generation from a single source of laser has attracted considerable attention among researchers over the last few decades. These multi-wavelength lasers are mostly proposed for Dense Wavelength Division Multiplexing (DWDM) application, but is also used for sensing and device testing purposes. In this paper, we review techniques proposed in multi-wavelength generation. Advantages and disadvantages of each technique are also discussed.

Keywords: *Multi-wavelength laser, Brillouin scattering, comb filter, cascaded modulator, arrayed waveguide gratings*

I. INTRODUCTION

Research on multi-wavelength laser generations has attracted considerable attentions from researchers worldwide over the last few decades. Generally, the multi-wavelength generation concept involves a single source of light that undergoes a multi-wavelength generation system block to generate multiple lasers at different wavelengths, as shown in Fig. 1.

Fig. 1General building block of a multi-wavelength laser generation system

Most multi-wavelength laser are proposedto replace multiple laser sources required in Dense Wavelength Division Multiplexing (DWDM) optical communication system, as shown in Fig 2. As can be seen in Fig. 2, multiple laser diodes (LD) operating at different wavelengths (λ) are required in a DWDM system. Hence, a system that can generate multiple laser sources at different wavelength as in Fig. 1 may offer savings to service providers.

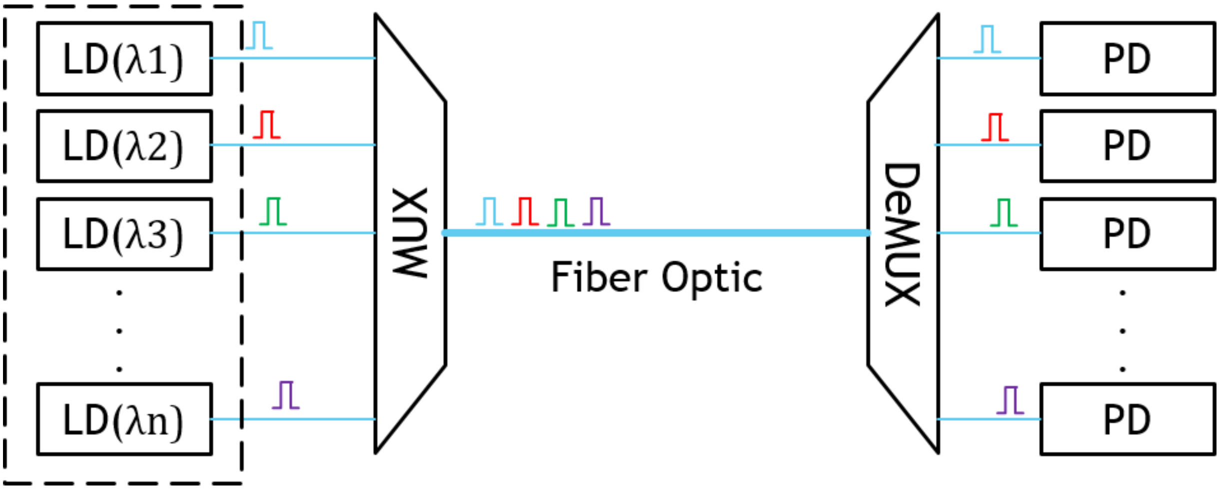

Fig. 2Typical Dense Wavelength Division Multiplexing system

Besides application in DWDM system, multi-wavelength lasers are also proposed for applications in sensing [1]–[3], device tester [4]andmicrowave generation[5], [6].

To achieve the multi-wavelength generation, several techniques are used, namely comb filter, Brillouin scattering technique,arrayed waveguide gratings and cascaded modulation technique. In this paper, we discussed all these techniques focusing on their principles as well as advantages and advantages.

II. COMB FILTER

Multi-wavelength laser generation based on this technique requires a broadband source that is sent to a comb filter as shown in Fig. 3. These comb filters are used to slice the broadband source into multiple smaller signals.

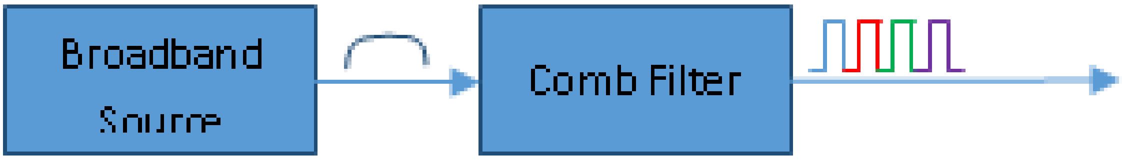

Fig. 3 General overview of comb filter based multi-wavelength laser

Research conducted in multi-wavelength using this technique mostly focused on type of broadband source and the comb filter design variations. Typical broadband sources used in this technique include Semiconductor Optical Amplifier (SOA) [7], [8], Raman amplifier [9], [10]and amplified spontaneous emission (ASE) from erbium doped fiber (EDF)[11], [12].In term of the comb filter design, there are multiple options, which are Lyot filter [13], Sagnac loop filter[14], [15], Mach-Zehnder Interferometer (MZI)[16] and Fabry Perot filter[17].

The advantages of multi-wavelength laser designed using this technique include simple design, mostly passive components and does not require long fiber optic. However, this technique mostly requires the use of polarization controller to control the polarization state of the light within the cavity to ensure optimum performance. This in turns resulted in a more complex system.

III. STIMULATED BRILLOUIN SCATTERING

Multi-wavelength laser generation using this technique exploits non-linear Brillouin scattering phenomena in fiber optic, and is commonly called multi-wavelength Brillouin Fiber Laser (MWBFL). Stimulated Brillouin scattering is a phenomenon named after Leon Brillouin, who predicted the phenomenon in year 1922 [18]. Brillouin scattering is a phenomenon where light scattering occurs due to thermally excited acoustic waves on a medium. Brillouin scattering can occur spontaneously at low light intensity resulting in a weak scattered light. At certain light intensity (called stimulated Brillouin scattering threshold, SBS_{TH}) however, the stimulated effect can take place where the optical field itself induces acoustic wave generation, reflecting most of the incident light. Stimulated Brillouin scattering (SBS) was first reported by Chiao et al in 1964, and has attracted a lot of attention ever since for multiple applications[18].

SBS involves the interactions of three waves, namely the input optical signal (called pump wave), acoustic wave and resulted scattered wave (called Stokes wave). This interaction in fiber optics can be explained with the help ofFig. 4. When its power exceeds the SBS_{TH}, pump wave at frequency ω_p induces traveling acoustic wave of frequency Ω_B. The traveling acoustic wave results in periodic refractive index variations, effectively making it a moving grating inside the fiber optic. The grating diffraction effects operates like a mirror, generating Stokes wave at frequency ω_s, propagating in the opposite direction. The generated Stokes wave has a down-shifted frequency of$\omega_s = \omega_p - \Omega_B$.

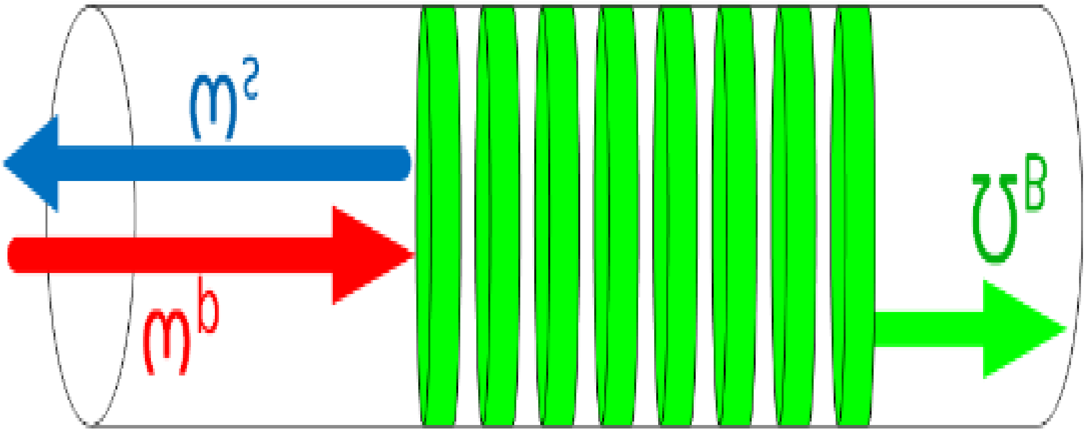

Fig. 4 Concept of Stimulated Brillouin Scattering

The principle behind MWBFL can be explained with the help ofFig. 5. A Brillouin pump (BP) as seed signal is injected into the laser cavity via a circulator. The BP then propagates towards the fiber optic cable. If the BP power exceeds the fiber optic's stimulated Brillouin scattering threshold (SBS_{TH}), then first-order Brillouin Stokes (BS_1) will be generated, propagating in the opposite direction of BP. In single mode fiber (SMF), BS_1 has a down-shifted frequency of ~10 GHz (+ ~0.08 nm wavelength) compared to BP. BS_1 will then travels back towards the optical coupler, where a fraction of its power is directed towards the output. The rest of the power however, is reflected by the mirror, and travels back towards the fiber optic (dash-lined BS_1). If the reflected BS_1 power still exceeds the SBS_{TH}, then second-order BS (BS_2) will be generated (10 GHz down-shifted frequency compared to BS_1) and propagates through the same route as BS_1. This process is repeated until BS_N does not have enough power to generate higher order BS_{N+}.

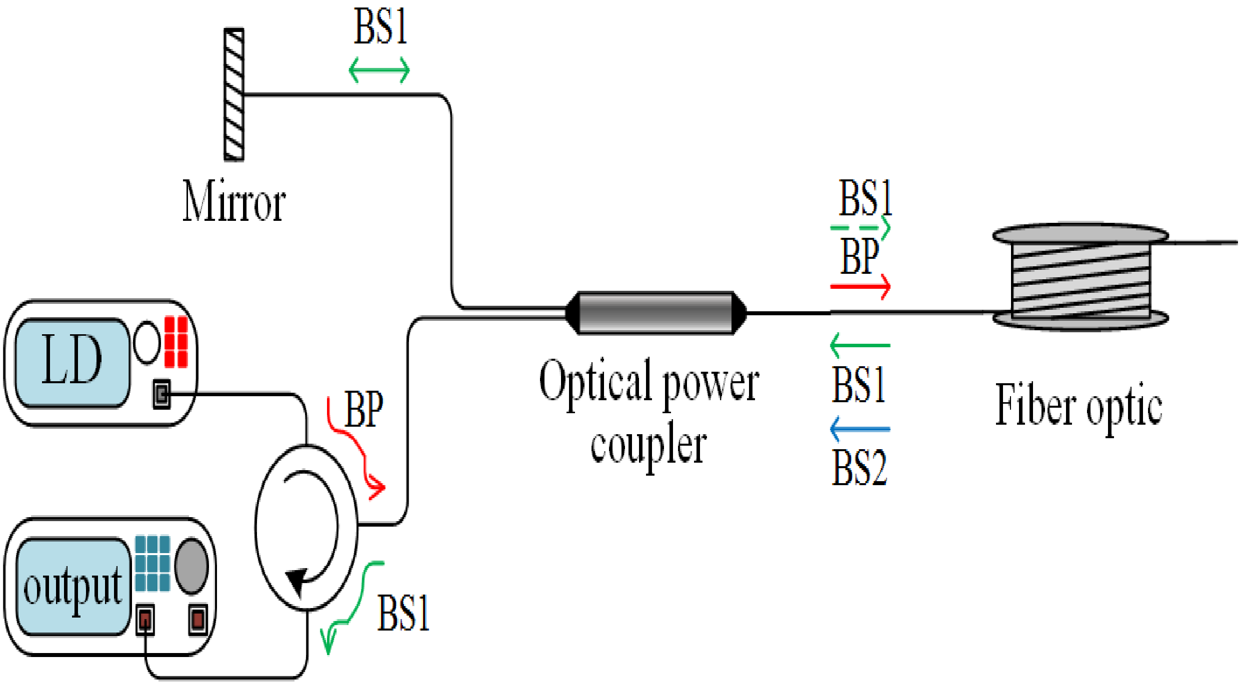

Fig. 5 Multi-wavelength Brillouin Fiber Laser Setup

To improve the performance, researchers incorporated hybrid amplifiers within the laser cavity, including erbium-doped fiber amplifier (EDFA) [19], Raman amplifier [20] and combination of both EDFA and Raman amplifier [21].

The advantage of SBS-based multi-wavelength laser generation is it offers flat outputs since the SBS_{TH} is almost constant. These multi-wavelength laser generation is also less complex since most of the components are passive and does not involve polarization controller.

The main disadvantage of this design is the spacing between each channels are fixed (~10 GHz) for SMFs, which is not aligned to the International Telecommunication Union (ITU) guideline for DWDM systems. Others include long fiber optic requirement and high pump power is required for the amplifiers to generate high number of channels.

IV. ARRAYED WAVEGUIDE GRATINGS

A simple technique to generate a multi-wavelength laser is to use array waveguide gratings (AWG) that operates as a wavelength selection filter [22]–[24]. An example is shown in Fig. 6, where a 32 × 32 AWG is used to slice a pulse source broadband source generated using a stand of dispersion flattened fiber[23].

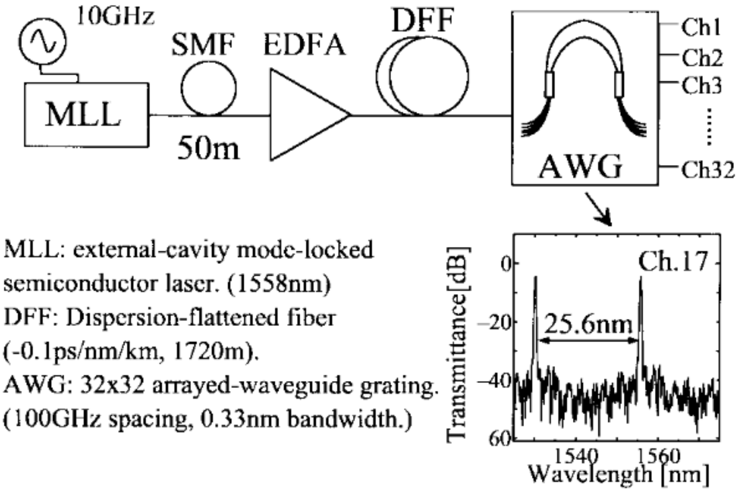

Fig. 6 Example of arrayed waveguide gratings based multi-wavelength laser generation[23]

Similar to comb filter technique, this technique requires the use of broadband source such as ASE from EDFA, super-continuum source and SOA. However, once these waveguide are fabricated, it is not possible to tune its spacing. Hence, while being simple, it does not offer much flexibility.

V. CASCADED MODULATOR TECHNIQUE

One unique technique of multi-wavelength generation is by using series of optical intensity modulators[25], [26]. One example of this technique is as shown in Fig. 7. In this design, a single laser source is fed into the first modulator. By carefully biasing the first modulator and controlling the power of the microwave signal, three or four channels of laser output can be generated due to the harmonics. The generated laser channels are then fed into a second intensity modulator, which will generate even more channels.

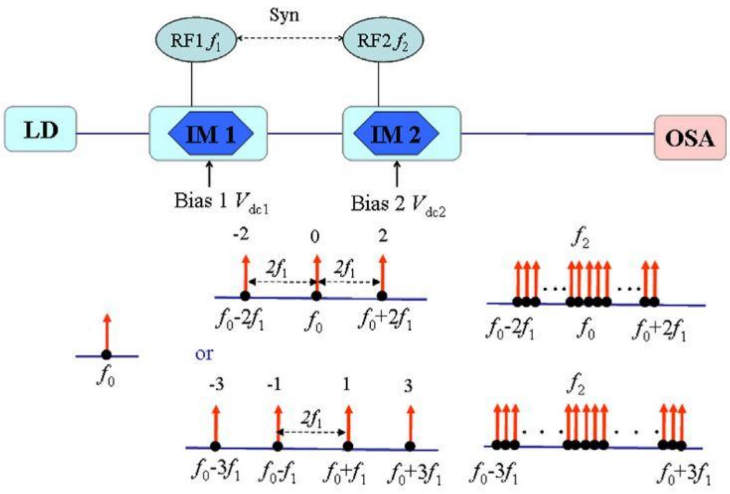

Fig. 7 Cascaded intensity modulators design example[26]

This technique offers flat output, flexible and easy channel spacing tunability (by adjusting the microwave frequency) as well as number of channels. However, this technique can be very expensive due to the cost of intensity modulators as well as requires a lot of active devices (microwave and bias signal).

VI. CONCLUSIONS

In this paper, we discussed techniques used in multi-wavelength laser generation which are comb filter, Brillouin scattering, arrayed waveguide gratings and cascaded modulator technique. Each of these techniques offers advantages over the other techniques, while suffering disadvantages in terms of cost, complexity and number of channels limitations.

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