# Review Paper of Array Waveguide Grating (AWG)

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**Abstract –** ***An array waveguide grating multiplexer and demultiplexer in particular is one of most successful optical filters and it is a key component of photonic networks and it is cost-effective devices. In this article I review the principles of AWG, describe its development in order to be used as DWDM filters, review its building technology and discuss the basics characteristics and parameters. Under the planar lightwave circuit (PLC) techniques AWG became available from different manufactory. The passband is the specified bandwidth symmetric around the ITU grid frequency where AWG parameters are defined.***

***Key Words:*** *AWG, DWDM, PLC.*

## 1. INTRODTION

Arrayed waveguide grating (AWG) multiplexer and demultiplexer is a very attractive planar device in wavelength division multiplexing (WDM) networks. It is capable of increasing transmission capacity of single optical fiber [1]. It has names such as waveguide grating router (WGR), phased array (PHASAR), or arrayed waveguide grating (AWG).
AWG was first proposed by Smit in 1988 [2]. Since the nineties the popularity of AWG has been rapidly increasing. The first devices operating at short wavelengths were reported by Vellekoop and Smit [3, 4, 5 and 6]. Takahashi et al reported the first devices operating in the long wavelength [7 and 8]. Dragon demonstrated the first NxN PAWG phased-array waveguide gratings [9 and 10]. Starting in 1993 an increasing number of system experiments involving AWGs have been reported [11, 12, 13, 14, and 15] and in1994 the first AWGs became commercially available in silica-on-silcon technology.

## 2. FIPER GRATING FILTERS

A grating is an element used for combining and separating individual wavelengths in WDM systems. A grating is a periodic structure or variation in the material that has the property of reflecting or transmitting light in a certain direction depending on the wavelength. Figure (1) defines various parameters for reflecting grating [16].

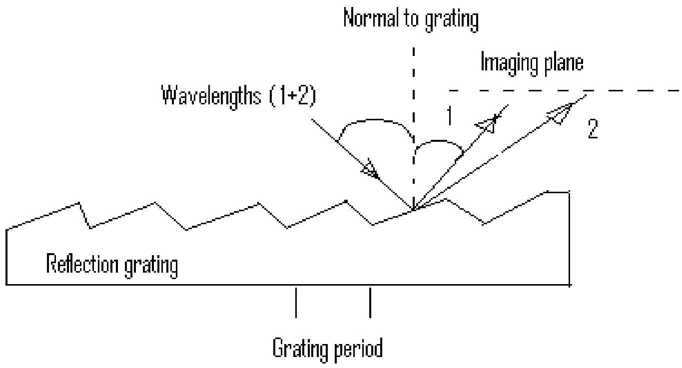


**Fig-1**: Basic parameters in reflection grating.

## 3. AWG PRINCIPLE

The silica-based waveguides are developed AWGs for use as DWDM filters. The configuration of an AWG multiplexer is shown in Figure (2). It consists of one input waveguide, several output waveguides and two focusing star couplers slab waveguides (also called free propagation region) which are connected via an arrayed-waveguides with a constant path length difference between them [17]. At the first free propagation region the ports of waveguide are placed along a circle of radius R, called the grating circle and input waveguides are placed along a circle of radius R/2, called the Roland circle which intersects with the grating circle [18]. When the light with different wavelengths is propagating through the first slab waveguide it is no longer laterally confined it becomes divergent [19]. Then the beam of light is coupled into the waveguide array and propagates through the individual array waveguides [20]. After traveling through the arrayed waveguides the light can interfere constructively at one focal point in the second slab. The location of the focal point depends on the signal wavelength (λ) because of the relative phase delay in each arrayed waveguide which is given by ($\Delta L$ /λ). The slabs and array waveguides respectively act as lenses and grating as shown in figure (3)Different wavelengths are therefore focused at different positions along the output edge of the second slab [19].

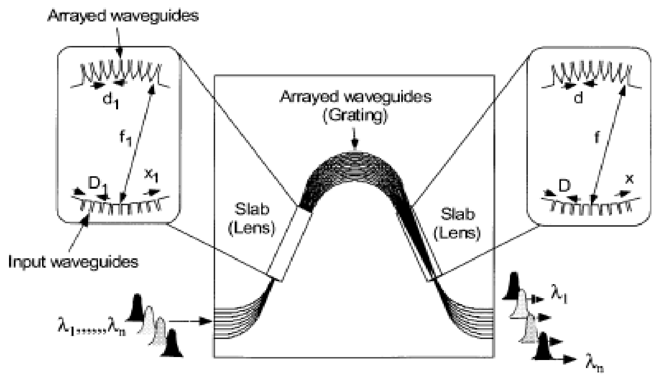


**Fig-2**: AWG multiplexer configurations

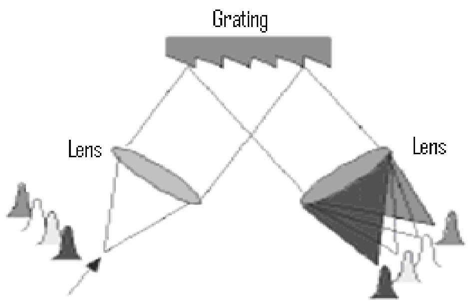


**Fig-2** : Micro-optics configurations of the same AWG.

### 3.1 Focusing

In figure (2) the first slab input waveguide separation is ($D_1$), the arrayed waveguide separation is ($d_1$), and the curvature radius is ($f_1$). In the output slab the output waveguide separation is ($D$), the arrayed waveguide separation is ($d$), and the curvature radius is ($f$). The input light at ($x_1$) radiates to the input slab and then propagates through the arrayed waveguides constructively interfering at one focal point ($x$) in the output slab. For two light beams passing through AWG the interference condition or grating equation can be written as:

$$B_s(\lambda_0)\frac{d_1x_1}{f_1} - B_s(\lambda_0)\frac{dx}{f} + B_c(\lambda_0)\Delta L = 2m\pi \qquad (1)$$

Where $B_s$ and $B_c$ respectively denote the propagation constants in the slab region and the arrayed waveguide, $m$ is an integer and $\lambda_0$ is the center wavelength of DWDM system. The focusing is obtained by choosing the length difference between adjacent array waveguides equal to integer number of wavelength. Then if

$B_c(\lambda_0)\,\Delta L = 2m\pi$ or

$$\Delta L = m\frac{\lambda_0}{n_c} \qquad (2)$$

is satisfied for $\lambda_0$, the light input position $x_1$ and the output position $x$ should satisfy the condition.

$$\frac{d_1x_1}{f_1} = \frac{dx}{f} \qquad (3)$$

Where $n_c$ is the effective index of the arrayed waveguide which is equal to the constants in an arrayed waveguide divided by the wave number in a vacuum and $m$ is a diffraction order [17].

### 3.2 Dispersion and Free Spectral Range

For determining the channel spacing one has to find the angular dispersion which is defined as the incremental lateral displacement of the focal spot along the image plane per unit frequency change. This is found by differentiating the grating equation (1) with respect to frequency. The result at θ = 0 should be considered according to equation (4) and figure (2).

$$\frac{d\theta}{dv} = -\frac{m\lambda^2}{n_s cd}\frac{n_g}{n_c} \qquad (4)$$

Where ($v$) is frequency and the group index ($n_g$) of the grating array waveguide is

$$n_g = n_c - \lambda\frac{dn_c}{d\lambda} \qquad (5)$$

The channel spacing ($\Delta v$) in terms of frequency is

$$\Delta v = \frac{x}{L_f}\left(\frac{d\theta}{dv}\right)^{-1} = \frac{x}{L_f}\frac{n_s cd}{m\lambda^2}\frac{n_c}{n_g} \qquad (6)$$

Also the channel spacing ($\Delta\lambda$) in terms of wavelength is

$$\Delta\lambda = \frac{x}{L_f}\frac{n_{sd}}{m}\frac{n_c}{n_g} = \frac{x}{L_f}\frac{\lambda_0 d}{\Delta\lambda}\frac{n_s}{n_g} \qquad (7)$$

Those last two equations define the frequencies or wavelengths for which the multiplexers can operate. Making $\Delta\lambda$ large the multiplexer and demultiplexer can respectively combine and split the optical signal with very small wavelength spacing. Grating equation shows the phased array is periodic for each path through the device, after each $2\Pi$ change in $\theta$ between the adjacent waveguides the field again will be at the same spot. In the frequency domain the period between two successive fields is called free spectral range (FSR) represented by the following relationship.

$$FSR = \frac{c}{n_g\left(\Delta L + d\sin\theta_i + d\sin\theta_0\right)} \quad (8)$$

Where $\theta_i$ and $\theta_0$ are diffraction angles in the input and output waveguides respectively and are measured from center of the array. The FSR depends on which input and which output ports the optical signal utilizes [16-2]. When the ports are across from each other, so that $\theta_i = \theta_0 = 0$, then

$$FSR = \frac{c}{n_g \Delta L} \quad (9)$$

### 3.4 Device characteristics

An AWG mux/demux device has lower loss, flatter passband, and easier to realize on an integrated optic substrate. An AWG has a reciprocal property that is: it can operate bi-directionally for either side input or output or both could take place at the same time. The wavelength routing property can only function for symmetrical input and output port AWG, where the angular separation angle at input and output are always equal. There is also a device property called vernier effect. A vernier AWG can be realized by changing at least one of the waveguide parameters in the input slab ($D_1$, $d_1$ and $f_1$) and those in the output slab ($D$, $d$, and $f$), using Figure (2). A vernier AWG can compensate for the possible center wavelength shift due to slight fabrication error in waveguide parameters ($n_c$), and ($\Delta L$). The vernier effect is only for the asymmetrical I/O ports AWG, where the angular separation angle at input and output are always not equal [21].

### 3.5 AWG APPLICATION

Array waveguide grating (AWG) is a passive wavelength-selective device, which provides basic multiplexing and demultiplexing WDM function [22]. Also there are more other functions in which AWG is used as wavelength routers, multiwavelength receivers, multiwavelength lasers, wavelength selective switches, and optical add drop multiplexers [20]. Examples of these different devices are shown in the figure (4):

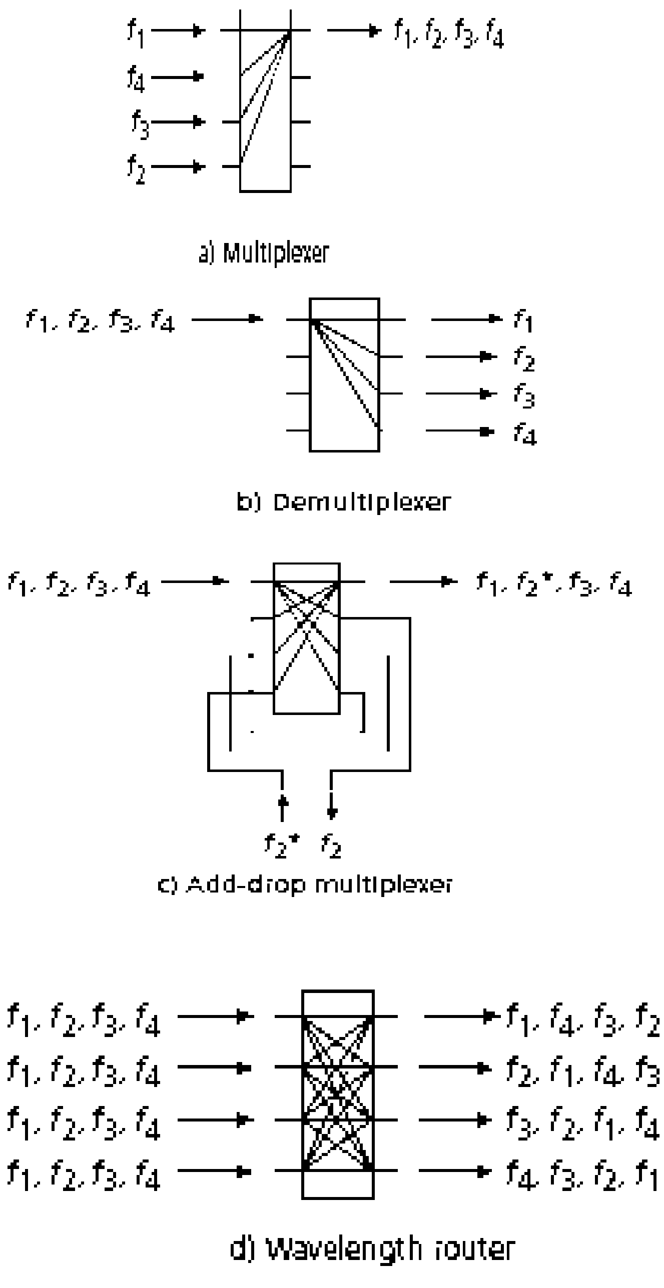


**Fig-4**: Different AWG devices: (a) Mux (b) Demux (c) Add-drop multiplexer (d) Wavelength router

### 3.5.1 Wavelength Routers

Wavelength routers were first reported by Dragone [9]. They provide an important additional functionality as compared to multiplexers and demultiplexers and play a key role in such more complex network and devices as add-drop multiplexers and wavelength switches [20]. The wavelength router is obtained by designing the input and output side of AWG symmetrically, which implies that the

FSR (free spectral range) should equal the number of ports times the channel spacing. This can be obtained from equation (9), by choosing

$$\Delta L = \frac{c}{N_g NFSR} \qquad (10)$$

A type of The AWG-based network architecture is illustrated in Figure (5). This is the cyclic AWG with D input ports and D output ports, whose free spectral range is equal to the number of ports times the channel spacing according to equation (10). There are N nodes in the network. At each AWG input port, an Sx1, S=N/D, combiner collects transmissions from the transmitters of S attached nodes. At each AWG output port, a 1xS splitter equally distributes the signal to S individual fibers that are attached to the receivers of the nodes. A compact silicon arrayed waveguide grating router (AWGR) for optical interconnects is experimentally demonstrated. The design, fabrication and characterization of this 4×4 AWGR with a 1250 GHz channel spacing and a 5 THz free spectral range are discussed. The loss of the AWGR varies from 2.5 dB to 5.5 dB and the crosstalk is better than -18 dB. The functionality of the AWG as a router and its good rotation property are also presented. This device has a compact footprint of 0.46×0.26mm2 [23].

### 3.5.2 Multiwavelength Integrated devices

The Multiwavelength integrated devices can be considered as multiwavelength receiver and multiwavelength laser.

A multi wavelength receiver is obtained by the integration of a demultiplexer with a photodiode array. Many different types of multiwavelength receivers are reported. An example is a Twinguide waveguide structure in which the passive region was obtained by locally removing the absorbing top layer. Integrated receivers have also been realized in buried waveguide structures and in polarization independent raised strip waveguides. A multiwavelength laser devise today is used as a source for WDM systems. Multiplexing of a number of wavelengths into one fiber is done using a power combiner or a wavelength multiplexer. Integrated multiwavelength lasers have been realized by combining a DFB laser array with linear frequency spacing with power combiner on a single chip. Using a power combiner for multiplexing the different wavelengths in a single fiber is a very tolerant method but it introduces a loss of 10logN dB, where N is the number of wavelength channels. The solution of this problem is combining a broad- band optical amplifier array with a multiplexer. If one of the semiconductor optical amplifiers (SOAs) is excited the device will start lasing at the passband maximum of the multiplexer channel to which the SOA is connected. All SOAs can be operated and modulated simultaneously. In this component the wavelength channels are automatically tuned to the passbands of multiplexer and coupled to the single output port with low loss. A problem in MW-lasers with small FSR is that the laser may start lasing in a wrong order and consequently at wrong frequency [20].

### 3.5.3 Add-Drop Multiplexer.

Add-drop multiplexers (ADMs) form a special class of wavelength selective switches. They are used for coupling one or more wavelength signals from a main input port to one or more drop ports by operating the corresponding switches [20]. The other signals are routed to the main output port together with the signals applied at the proper add ports. The first add-drop multiplexers have been realized in silica-on-silicon waveguides. Recently reconfigurable InP-based ADM has been reported. In addition to ADM, optical networks require the ability to root high-speed optical signals in a transparent fashion. This task can be accomplished by an NxN optical switch. A switch of complexity which increases linearly with N can be constructed by exploiting the wavelength domain. In this approach the optical input signal is first converted to the wavelength and routed towards the desired output port. This task can be done by AWG integrated with other optical devices as in figure (5) Add-drop multiplexers of two different configurations [24].

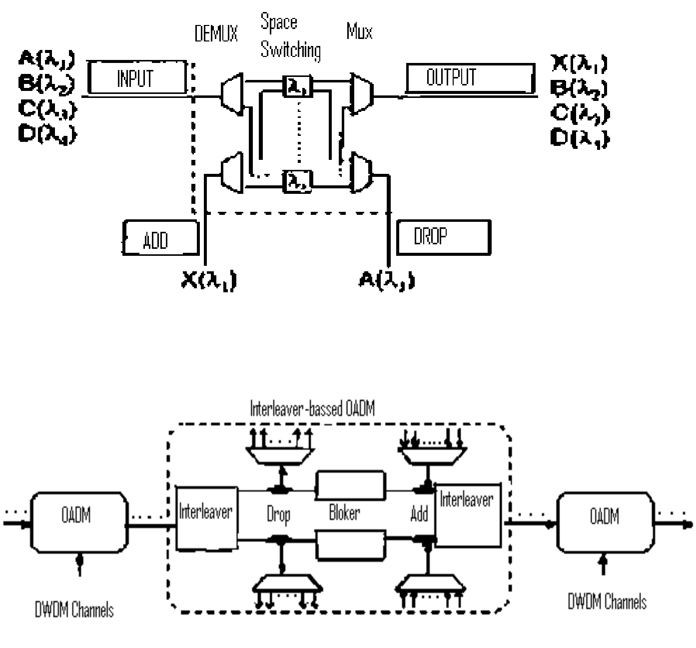


**Fig-5**: Different configurations of add-drop multiplexers

### 3.6 PASSIVE OPTICAL DIFFRACTION

Optical multiplexers and Demultiplexers are based on passive optical diffraction. AWG is an example of these techniques. Diffraction is the predictions of the deviation of geometrical optics. The wave transverse plane is the plane perpendicular to the direction of the wave travel and it is very important for diffraction analysis when the power and intensity of light beam are used interchangeably. Diffraction theory show that the beam does not converge to a point but it reduces to a central spot of light surrounded by rings of steadily diminishing intensity. Actual light sources often produce nonuniform beams. The intensities vary across the transverse plane. A particularly important transverse pattern is the Gaussian distribution. The Gaussian intensity distribution is given mathematically by

$$I = I_0 e^{-2r^2/w^2} \quad (11)$$

Where $e$ is the base of the natural logarithm that equal to 2.718, $I_0$ is the intensity at the center of the beam, at $r = 0$. The accepted radius of the spot is the distance at which the beam intensity drops to $\frac{1}{e^2} = 0.135$ times its peak value $I_0$, which is called the spot size. The spot size in the focal plane is

$$w_0 = \frac{\lambda f}{\pi w} \quad (12)$$

The intensity distribution is

$$I = I_0 \exp\left(-2r^2/w_0{}^2\right) \quad (13)$$

For longer distances diffraction theory shows that the beam diverges at a constant full angle given by

$$\theta = \frac{2\lambda}{\pi w} \quad (14)$$

Where $\theta$ is the diffraction angle measured in radians [25].

## 3.7 FLATTENED PASSBAND RESPONSE

The dispersion at any position along the focal length with respect to wavelength $\lambda$ is almost constant. The transmission loss of the AWG increases around the center wavelength of each channel. The nonrectangular passband characteristic of AWG will allow wavelength-shift tolerance. Moreover since optical signals are transmitted through several filters in the WDM networks, the passband width of each channel becomes much narrower than that of single-stage AWG filter therefor the flattened spectral response is required for AWGs. The flattened passband is used to break the symmetry of AWG by modifying the input, the grating array waveguides, and the output or by integrating with other passive optical devices. Many techniques are used for making AWGs with flattened top passband for example using y-branches, multimode interference coupler, or short parabolic horns on the input / output star couplers inlets or modify the grating arm lengths and transmissivities. Of course all these techniques increase the insertion loss. Others use multiple Rowland circles, double – phased arrays, or apply the phase – transfer techniques such as a complex aperture synthesis techniques to get a flat AWG's flattened passband by shaping the phase transfer. Some use multimode waveguide at the receiver side. Others can integrate AWG with Mach-Zehender filters to solve the problem of flattening. Some use interleavers to separate the channels to wider channel spacing and use Gassuian-passband AWG's with large channel spacing to demultiplex each channel set. Others use the cascade of two AWG's, where the free spectral range of one is equal to the channel spacing of the other [21]. In this paper, a 17 × 17 arrayed waveguide grating (AWG) multiplexer with flat spectral response has been designed and fabricated by using FPE polymer materials. Experimental results show that the central wavelength is 1550.86 nm, and 3-dB bandwidth is about 0.478 nm, insertion loss is 10.5 dB, crosstalk is about –20.5 dB. Simulated results show that fabrication processing result in the shift of the transmission spectrum compared with the device theoretically designed. Furthermore, the transmission characteristics are discussed, and some efficient ways are reported [26].

### 3.8 THERMAL AWG's

The center wavelengths for each channel in a conventional AWG depend on the temperature due to the thermally induced refractive change in silica-based waveguides. The AWG's must be controlled with a heater of a thermoelectric device to stabilize the center wavelength. The temperature compensation technique used to suppress the temperature dependence. Many other techniques are reported for solving this problem [27].

## 3.9 POLARIZATION

The electric field of a light beam can have several directions. One of these is the direction of its travel and the other is that of the electric field vector. The wave travels in the z direction, and the electric field vector points in the x direction. An electric field that points in just one direction is said to be linearly polarized, because it always points along the same single line. The electric vector is always perpendicular to the direction of a plane wave in an unbounded medium. The E field in the figure could also point in the y direction while traveling in the z direction. The actual direction of polarization is determined by the polarization of the light source and by any polarization-sensitive elements through which the beam passes. It is also possible for two waves to simultaneously travel in the z direction, one polarized in x direction and one polarized in the y direction. These two waves would be independent of each other because of their orthogonal polarization. The term mode refers to the different ways a wave can travel in a given direction. Other modes are possible, having polarizations in xy plane at the same angle to the x or y axis. A wave is unpolarized if its electric vector varies randomly in direction. Waves in most optic fibers are unpolarized. In a guided structure, such as an optic fiber, many modes can exist. Polarization is one of the differences among modes in a waveguide which play an extremely important part in determining the design and capabilities of optic communications system [25]. The starting point when defining the performance of AWG is to look at its amplitude response for both the transverse electric (TE) and the transverse magnetic (TM) polarization states. The maximum and minimum transmission points of each polarization at each wavelength can be determined. There are many methods used to obtain the amplitude response of AWG. The most common is to connect a tunable laser and a polarization controller to the input waveguide and one or more power meters to the output waveguides. TE and TM measurements can be obtained by setting the input polarization state to TE and then to TM using the polarization controller and recording one scan for each state. There are three different polarizations dependent loss (PDL) that affect the AWGs performance one is the PDL at the international telecommunications union (ITU) center wavelength, second PDL specified the worst-case PDL across the entire passband and the third specifies the difference between peak transmission of the TE and TM polarization states. The clear window is defined as a band of wavelengths around each International Telecommunications Union ITU center wavelength. The width of the window is chosen to be the range of wavelength that the signal could occupy accounting for the bandwidth of the signal and drift in the wavelength of the laser. When quoting the performance of AWG all specifications quoted are the worst case values within any clear window of the device [19].

### 3.10 AWG PARAMETERS

The starting point for defining the AWG performance is its spectral response to both transverse electric and transverse magnetic polarization states. The maximum and minimum transmission points of each polarization state over the wavelength range of interest can be used to obtain equivalent information. The insertion of optical component into an optical system is usually accompanied with system performance degradation. For AWG application, a number of parameters related to both amplitude and phase response of the device must be considered.

#### 3.10.1 ITU Passband

The International telecommunications Union (ITU) has adapted standards for optical communication that specifies the certain standard frequencies to be used for identify and specify WDM channels. ITU channels begin at 190.00 THz (channel 0.1577.86 nm) and increments by 0.10 THz for each subsequent channel. It is usually spans over the C-band (1520 – 1570 nm). The passband is the specified bandwidth symmetric around the ITU grid frequency where AWG parameters are defined.

#### 3.10.2 Crosstalk

The adjacent crosstalk of a channel is the highest transmission within an adjacent passband referenced to the lowest transmission within the selected channel passband. The highest and lowest transmissions are determined for any possibly different polarization states within each passband.

The non-adjacent crosstalk of a channel is the highest transmission within a non-adjacent passband referenced to the lowest transmission within the selected channel passband. The highest and lowest transmissions are determined for any possibly different polarization states within each passband.

The Maximum Integrated Crosstalk of a channel is the sum of the maximum crosstalk values from all other channels. This occurs when all signals independently align with the wavelengths and polarizations of maximum crosstalk. Maximum integrated crosstalk is most noticeable in very narrow spectral signals since all of the optical power must be precisely at the wavelengths of maximum crosstalk. The Average Integrated Crosstalk of a channel is the sum of the average crosstalk from all other channels. The average crosstalk of a channel can be described as the mean of the maximum transmission in the passband of that channel. Crosstalk values are referenced to the mean of the minimum transmission in the chosen channel passband. Average integrated crosstalk represents the worst-case total crosstalk that could occur for a signal with its power distributed uniformly across the passband. It is a more appropriate measure of crosstalk for high bit rate signals because these higher bit rates cause the power in the signal to be spread across a wider spectrum [28].

## 4. LARGE SCALE AWG SYSTEMS

The previously mentioned growing demand for more channels at reduced cost has culminated in the need to fabricate filters with even narrower passbands and larger port counts. Planar lightwave circuit ( PLC) devices consisting of fiber-matched silica-based waveguides on Si can meet this demand because they can provide various large-scale key devices for photonic networks. PLC-type devices can also offer long-term stability and be mass produced [27]. These PLC devices include wavelength N X N multiplexers/demultiplexers, optical add/drop or cross-connect switches, multiwavelength light sources for WDM transport networks, programmable filters for high-speed transmission systems, 1/N optical power splitters, optical couplers, and 1300/1550 nm WDM optical modules for access networks. The arrayed waveguide grating multi/demultiplexer in particular is one of the most successful optical filters, and it is a key component of photonic networks.

Arrayed waveguide grating (AWG) is a cost-effective optical filter that is constructed to make a large-scale wavelength multiplexer/demultiplexer. AWG based on planar lightwave circuit (PLC) technology can be fabricated as a single device. Large-scale AWG with up to 256 channels has been reported by using 1.5% waveguides with a low propagation loss of 0.05dB/cm and a small minimum bending radius of 2mm. A 400-channel AWG with 25GHz spacing has been reported and this may play an important role in future dense wavelength division multiplexing (DWDM) systems ranged from 1530 to 1565 nm [29]. Many WDM systems are designed to transmit their multiple channels in the C-band. C-band is too small for supporting high-channel-count systems, so the use of the long band (L-band) for wavelengths above 1565 nm is now allowing the number of channels in systems to be increased to more than 160 channels. The addition of channels in the short band (S-band) below 1490 nm is opening the doors for low-cost metropolitan WDM implementation around the 1310 nm region [30-39]. To multiplex/demultiplex 400 channels over C-band and L-band range needs more than 1000 arrayed waveguides with long (47mm) slab waveguides. Since these design parameters increase the AWG size to as much as 124mmX60mm, a 6-inch Silicon wafer is used as the substrate and the PLC fabrication process to suit this large wafer is adjusted. Good demultiplexing properties are obtained over the full wave-length range of the C- and L-bands. The 400-channel AWG can support a transmission capacity of 4Tbit/s at a bit rate of 10Gbit/s in a single configuration with the on-chip losses ranging from 3.8 to 6.4 dB and with the far-end crosstalk reduced to-30dB [29].

## 4.1 Planar Lightwave Circuit (PLC)

Optical waveguide components (OWC) become available from a variety of manufacturers and venders worldwide. These OWCs are deployed in commercial systems such as advanced transmitters and modulators used in fiber optic-based CATV and long-haul telecommunications systems, or in passive devices such as AWG. These OWC devices are based on planar optical waveguides in which light is confined to substrate-surface channels and routed onto the chip. These channels are typically less than 10 microns across and are patterned using microlithography techniques. With appropriate optical circuits based on these channel guides both passive functions such as power splitting from one to several channels and active functions such as modulation can be performed on the light. The primary materials used in the commercial market are glass or fused silica (bulk $SiO_2$ or $SiO_2/Si$) for passive devices and lithium niobate ($LiNbO_3$) for active devices. The most prominent feature of silica waveguides is their simple and well-defined waveguide structure. This allows photonics component manufacturers to produce multibeam or multistage interference devices such as arrayed-waveguide gratings (AWGs) and lattice-form programmable dispersion equalizers. A variety of passive planar lightwave circuits (PLCs), such as NXN star couples, NXN AWG multiplexers, thermo-optic matrix switches, and variable optical attenuator arrayed waveguide grating multiplexer (V-AWG) and a high performance (ROADM) router optical add drop multiplexer node have all been developed in this way [31-40 and 32- 41]. In this way PLCs using silica-based optical waveguides are fabricated on silicon or silica substrate by a combination of flame hydrolysis deposition (EHD) and reactive ion etching. Fine glass particles are produced in the oxyhydrogen flame and deposited on the host substrate (Si or $SiO_2$). After under cladding and core glass layers are deposited the wafer is heated to high temperature for consolidation. The circuit pattern is fabricated by means of photolithography and reactive ion etching (RIE). Finally, core ridge structures are covered with an over cladding layer and consolidated again. Since the typical bending radius R of a silica waveguide is between 2 and 25 mm, the chip size of the large-scale integrated circuit (IC) becomes several square centimeters. Therefore, propagation loss reduction and uniformity of refractive indices and core geometries throughout the wafer are essential. Propagation loss of 0.1dB/cm is obtained in a two-meter long waveguide with $\Delta = 2\%$ index difference (R=2mm), and loss of 0.035 dB/cm is obtained in a 1.6-meter long waveguide with $\Delta = 0.75\%$ index difference (R=5mm) [40]. In the fabrication of AWG based on planer light wave circuit (PLC) technologies the crosstalk performance is mainly affected by the phase errors in the arrayed waveguide region. These phase errors are the deviation from designed optical path lengths of the arrayed waveguides [33]. For good isolation characteristics the fluctuations of index difference, width, and height of the waveguides should be kept small. In particular the fluctuations of refractive index and film thickness depend to some extent on intrinsic characteristics of the deposition process even if the base material size and specifications of the PLC device are identical. Therefore optical device manufacturers should be considering optical film qualities such as propagation loss, birefringence, refractive index uniformity, and thickness uniformity, as well as cost and availability of the process. For silica-based PLCs, flame hydrolysis deposition (FHD) and plasma-enhanced chemical vapor deposition (PECVD) are mainly used and the preference can be varied with the target devices to be fabricated. For example, FHD shows a better step coverage property than PECVD, which is important for hybrid integration, while PECVD is more suitable than FHD for the devices that require strict phase-error control. When an AWG is fabricated using FHD, the direct measurements of film index and thickness can be a fast and effective tool for the reduction of the crosstalk of AWG. It can provide data of high resolution and accuracy enough to characterize the crosstalk [32].

## 5 AWG CROSSTALK REDUCTION

One of the important issues in designing multichannel detection systems is the level of crosstalk. The system performance degrades whenever crosstalk leads to a transfer of power from one channel to another. The crosstalk becomes the major limiting factor in the sensitivity of the array in a DWDM optical communication system. Optical crosstalk arises when the light incident on one channel is coupled to another channel (usually the adjacent one) by reflections or poor fiber-to-photodetector coupling. The adjacent channel crosstalk in 1550 nm InP-based monolithically integrated photoreceiver arrays can be reduced to -35dB by using a metal shield integrated to each channel [34]. The crosstalk in AWG is caused by the sidelobes and scattered light of the focused beam in the interface between the second slab waveguide and output waveguides [35]. Several techniques are used to improve the total crosstalk performance of a multiplexer and demultiplexer. One such a technique is crosstalk cancellation from other channels by weighting and summing the photocurrents of desired channel and several adjacent interference channels. A reduction of crosstalk component can also be realized by introducing a wavelength selective filter, or by subdivision and rearrangement of signals. These techniques require several kinds of components or real time control, so they are unsuitable for a large multiplexer and demultiplexer with high speed operation. Alternatively to improve the crosstalk performance of an AWG narrowing the channel bandwidth is found to be effective because crossover of AWG transmission profiles is prevented. This requires the accurate adjustment of signal wavelengths. It is obvious that small AWG's offer a simple but effective method of reducing crosstalk at the cost of decreasing the number of available channels. Crosstalk reduction is also possible by reducing the slowly varying phase fluctuations. Using this techniques for AWG 64 channel with 50GHz spacing, gave the average crosstalk and far-end crosstalk (nonadjacent crosstalk) of less than -35 for the first and -40dB for the latter [35].

### 5.1 Cascade AWGs

Arrayed waveguide gratings (AWGs) founded on silica-based planar light wave circuit (PLC) technology are playing a key role as practical multiplexers and demultiplexers in high-channel-count DWDM systems with a large transmission capacity. However, the optical performance of AWGs tends to worsen as their scale is increased because the accumulated crosstalk increases in proportion to channel number. This means that accumulated crosstalk in large scale AWG obstruct signal transmission even if it has a good background (nonadjacent) crosstalk level around -40dB. The cascade connection techniques are used to avoid this problem with large scale AWGs. It is a way of reducing the crosstalk of conventional AWG filter. The practical development of cascade connection technique necessitates its application to a large-scale multiplexer and demultiplexer in which the accumulated crosstalk is a critical problem [36]. The cascade connection is shown in Figure (6). It consists of three PLC elements: an input AWG1, a hybrid integrated optical gate array circuit (OGA) (this is hybrid integrated by four channel 1550nm spot-size converted semiconductor optical amplifiers (SS-SOA's) used as optical gates), and an output AWG2. Input signals with different wavelengths of ($\lambda_1 - \lambda_2$) are demultiplexed by the AWG1 and fed to the OGA and then fed to AWG2. Finally the signals are demultiplexed by the AWG2 into the output port. The PLC elements were fabricated separately, and then attached direct by PLC-PLC to reduce the circuit size [37].

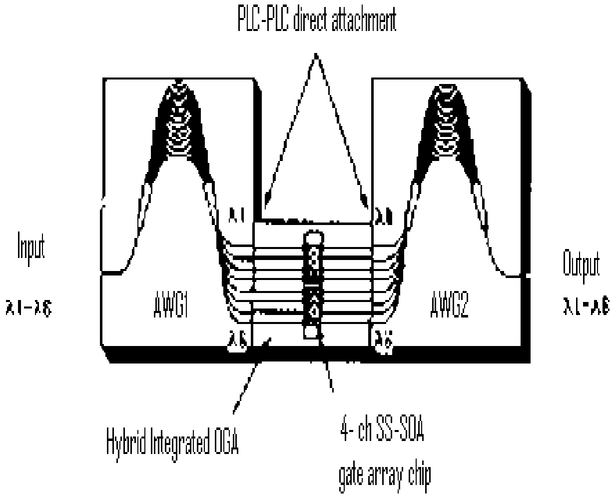


**Fig - 6**: AWG (PLC-PLC) cascade connection

## 6. CONCLUSIONS

In this article I presented the building technology of AWG and review its advantages. An AWG is a power full multiplexing and demultiplexing devices for optical signal through a long hall communication distance based on DWDM with acceptable accumulated crosstalk.

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