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# Semiconductor Optical Amplifiers (SOAs) in CWDM Systems

Applications Note No. 0004

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Coarse wavelength division multiplexing (CWDM) is a low cost route to providing connection flexibility and increased throughput at the metro and enterprise layers of the network. The wide spacing (~20nm) between a modest numbers of wavelength channels (8 to 16) allows the utilisation of a new class of lower cost components, yielding as much as a 30% saving on traditional DWDM componentry e.g. un-cooled DFB lasers which although drift with temperature, still fall within the pass-band of wide, flat-top mux/de-mux stages. The ITU has defined a CWDM standard (G.694.2) covering the entire the low loss transmission window of standard single mode optical fibre (1260nm to 1620nm) (Figure 1).

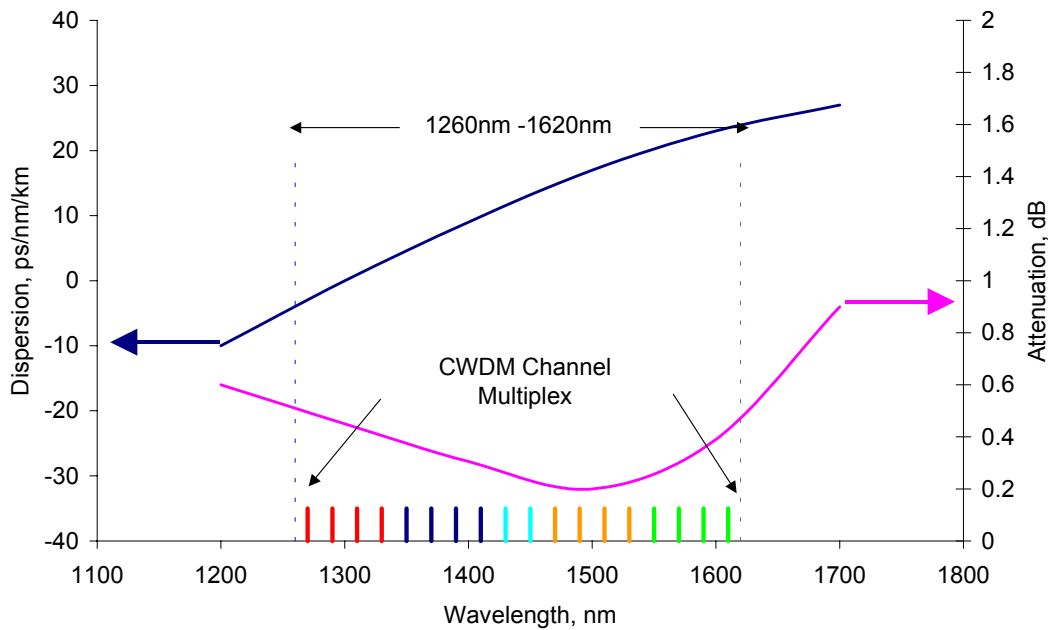


Figure 1: The relationship between the ITU-defined CWDM multiplex and the low loss transmission window of optical fibre. Also shown is the dispersion for standard single mode fibre (SMF28).

To extend the capacity and distance of CWDM systems (>100km) requires a low cost optical amplifier operating across the entire optical bandwidth. The SOA is the only viable technology that can be deployed to meet these expanding applications. The intrinsic characteristic of the SOA permits access to an extended gain bandwidth, able to provide gain between 1260nm and 1620nm. Erbium-based amplifiers (EDFAs) can operate in the C band (1530nm-1562nm) and L band (1570nm-1610nm) and therefore only cover, at most, two CWDM channels at a time. Furthermore EDFAs cannot amplify channels in the lower, 1300nm, portion of the application space. Figure 2 summarises the application scenarios for SOAs in CWDM.

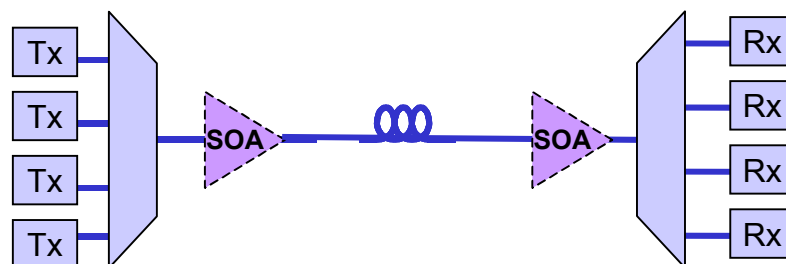


Figure 2: Application scenarios for SOAs in CWDM, highlighting a booster, pre-amplifier approach or indeed a combination of both.

## Semiconductor Optical Amplifiers

**Multi-wavelength operation:** the SOA can operate in single and multi-channel environments. Operation in the linear region of the SOA permits error-free transmission of multiple channels. This operating space is defined by the input power levels, the gain and the output saturation power of the device. For example for a +10dBm output saturation (average) power (at the 3dB gain compression point) for a gain of 15dB, the maximum (total) input power would be -5dBm. The number of channels, the output power per channel and the available output saturation power level will then define the gain required from the SOA.

For further details of the performance of the SOA in multi-channel scenarios relevant to CWDM networking see "Kamelian Application Note No. 0003: SOAs in Multi-Channel Environments".

**Linear operating regime:** in amplification, the linear region is the preferred operating regime since an exact, amplified replica of the input is required. Operating an SOA outside this region causes interference noise since at high output powers, the gain saturates and compresses. The resulting gain modulation causes inter-symbol interference or patterning in the time domain, because the gain recovery time of an SOA is typically of the same order as the data modulation speeds. Thus one of the key operating issues to ensure linear functionality is the management of the input power levels in order to control the degree into which the device is driven into saturation, especially crucial in multi-wavelength applications where a band of channels are amplified, sharing the available output power. For more detail on the effect of linearity of performance refer to Kamelian Application Note No. 0003: "SOAs in Multi-Channel Environments".

**Output saturation power:** for more detail on the output saturation power performance of typical SOAs refer to Kamelian Application Note No. 0001: "SOAs as Power Boosters". Also detailed is the wavelength dependence of the output saturation power, especially relevant in multi-channel operation. This parameters can be optimised for any particular application by accurate movement of the gain peak. In booster applications, the output power is the primary design parameter of interest.

**Chirp in gain compression:** for more details on the evolution of chirp as a function of gain compression refer to Kamelian Application Note No. 0001: "SOAs as Power Boosters". In multi-channel scenarios, the level of chirp produced is proportional to the amount of gain compression the signals are subject to. This is as a consequence of the gain modulation causing patterning in the time domain on each of the channels.

**Four Wave Mixing (FWM) in gain compression:** with multi channel operation in gain compression, the many optical signals subject to dynamic gain modulation produce mixing products due to the non-linear characteristic of the SOA which beat at a frequency determined by their optical frequency separation. The resultant crosstalk can produce significant power penalties due to coherent beat noise phenomena. For more detail on the performance of SOAs in this respect refer to Kamelian Application Note No. 0003: "SOAs in Multi-Channel Environments". For CWDM, the wide channel spacing between channels is such that the level of FWM-generated crosstalk is negligible.

**Gain transient behaviour in compression:** another consequence of operating in gain compression concerns the amplification of bands of wavelengths under dynamic network conditions. Dynamic power changes on the dropping and adding of wavelengths causes gain transients on the remaining channels. For more detail on the performance of SOAs in this respect refer to Kamelian Application Note No. 0003: "SOAs in Multi-Channel Environments". Operation within the linear region of the SOA obviates unwanted transients as a consequence of variations in the input power level. This is only of relevance when dynamic CWDM systems are deployed.

**Wide optical bandwidth:** SOAs exhibit a ~80nm optical gain bandwidth at the 3dB drop from the peak gain. Access to a wider bandwidth is possible if the minimum system gain required (at the extremities) is lower e.g. as much as 110nm at the 5dB point down from the gain peak (Figure 3). Centring the gain peak very accurately during the material growth stage means that the SOA can meet the amplifier needs for all of the CWDM spectrum in bands of 80nm. Therefore four variants of the standard SOA will satisfy the amplification needs across that spectrum (Figure 4). All variants feature the same device structure fabricated under the same processes, the only difference being the start material characteristics; hence performance, cost and volumes are not compromised.

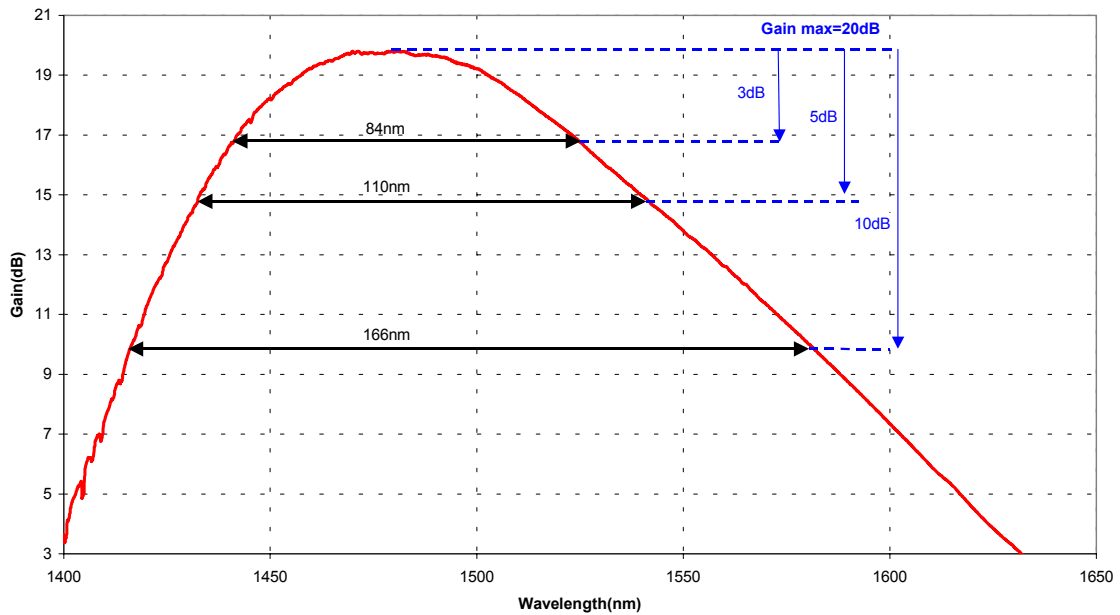


Figure 3: Gain vs. wavelength for a typical SOA, in this case centred on 1465nm.

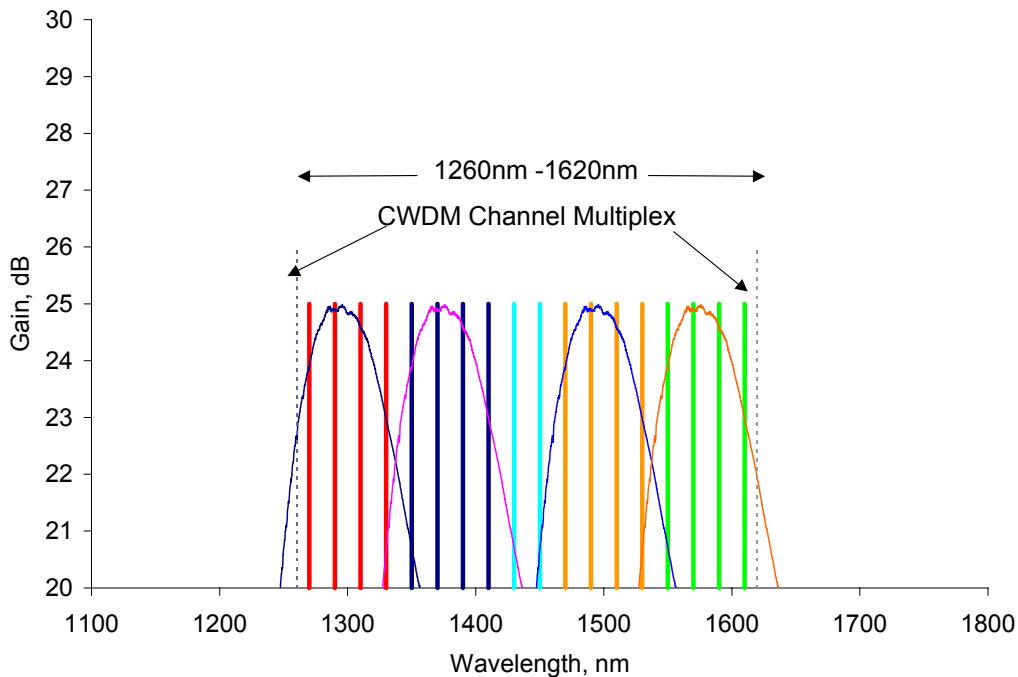


Figure 4: A typical SOA gain bandwidth profile (see Figure 2) repeated but centred at different wavelengths thereby addressing the entire CWDM spectrum with four SOAs.

**Noise figure (NF):** the amplification process is always accompanied by spontaneous emission, where photons of random phase and polarisation are added to the signal. The noise performance of an optical amplifier is characterised by the NF, defined as the amount of degradation in the signal to noise ratio caused by the amplification process. The NF performance of typical SOAs is defined in Kamelian Application Note No. 0002: "SOAs as Pre-Amplifiers". A low NF is vital in pre-amplifier scenarios.

**Polarisation dependent gain (PDG):** in any optical communication system the state of polarisation at any in-line component is unknown, since installed optical fibre does not preserve the state of polarisation. Thus, typically, the SOA has to be polarisation insensitive. Through chip design know-how, very low polarisation dependent gain (<0.2dB) has been achieved. For the wavelength dependence of PDG refer to Kamelian Application Note No. 0002: "SOAs as Pre-Amplifiers". A low PDG is required if the SOA is deployed after a long transmission link where the polarisation state is random with time.

**Data rate transparent:** the SOA is able to amplify at data rates ranging from Mbit/s up to and beyond 40Gbit/s. In this respect it is a future proof technology compatible with any upgrade scenario since it is also protocol independent.

**Small form factor, amenable to integration:** the SOA is housed within a standard 14-pin butterfly package, the subject of a multi source agreement (MSA) with other leading SOA suppliers which guarantees system providers with common optical/mechanical specifications. The size of the package represents a significant improvement on competing optical amplifier solutions. Longer term, Kamelian's know-how in on-chip mode expansion technology promotes a manufacturable solution to the integration of the SOA with other components to yield low cost, highly functional modules.

The Kamelian logo consists of the word "kamelian" in a lowercase, sans-serif font. The letters "k", "a", "m", "e", and "l" are purple, while "i", "a", "n" are blue. A small green registered trademark symbol (®) is positioned to the upper right of the "n".

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