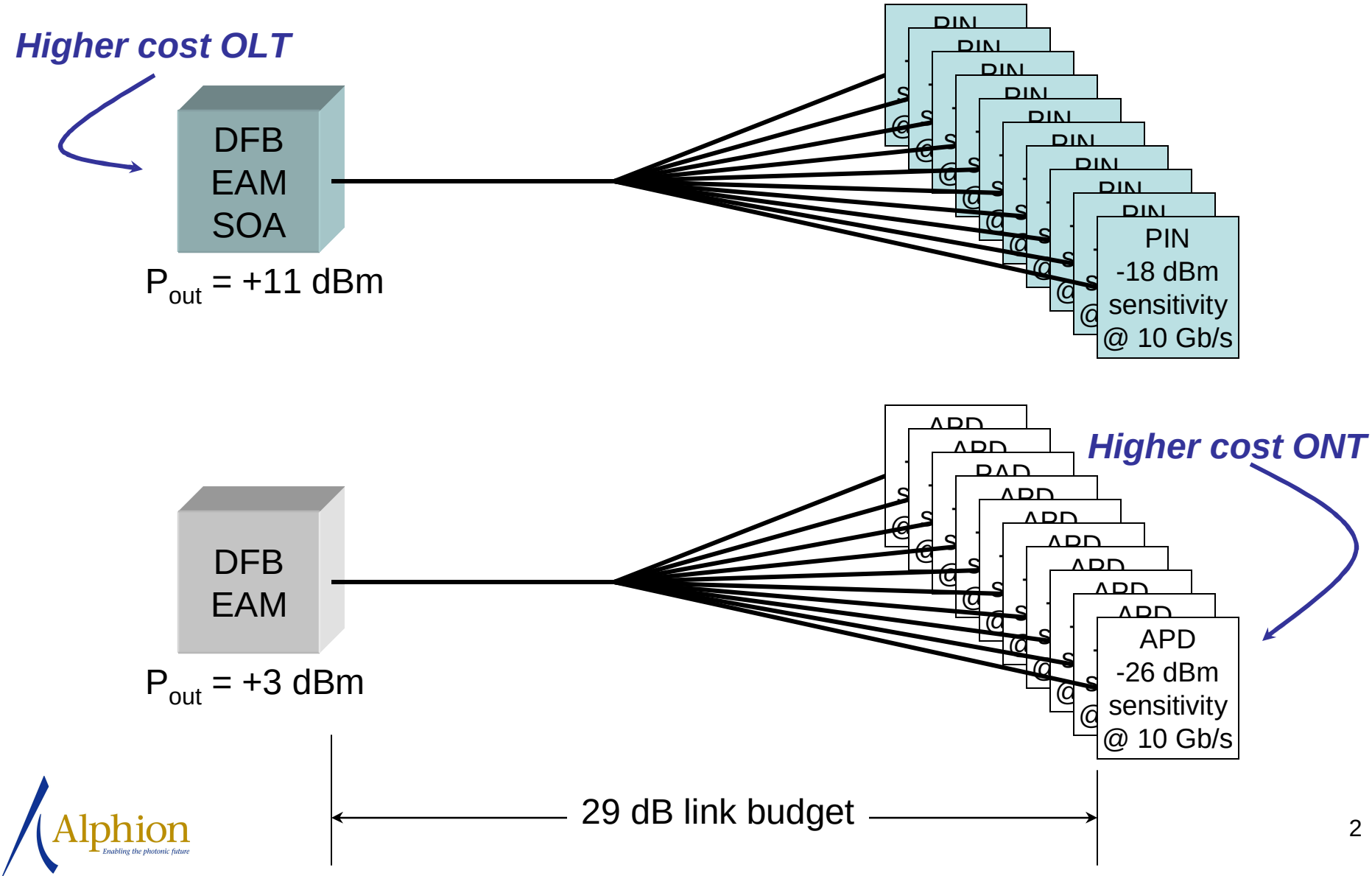
Semiconductor Optical Amplifiers – High Power Operation

Boris Stefanov, Leo Spiekman, David Piehler
Alphion Corporation

IEEE 802.3av Task Force Meeting, Orlando, 13-15 March 2007

Two 10 Gb/s downstream solutions



SOA vendor survey

From:
http://www.ieee802.org/3/av/public/2006_11/3av_0611_lee_1.pdf
(November 2006 meeting)

Availability of SOAs

- Off the shelf in the spectral band of 1550 nm and 1310 nm
- Saturation power is > 11 dBm typically, and 14 dBm maximum
- Gain is > 10 dB typically, and 22 dB maximum

Vendor	Wavelength (nm)	Gain (dB)			3dB Saturation Power (dBm)		NF (dB)
		min	typ	max	min	typ	typ
A	1310		14.0			11.0	8.0
B		18.0	22.0			10.0	7.0
		13.0	16.0		10.0		7.0
C		10.0			8.0		6.0
		16.0			8.0		6.0
A	1550		14.0			13.0	7.0
		4.0		8.0		13.0	7.0
B		10.0	13.0		12.0	14.0	8.0
C		12.0	15.0			10.0	9.0
		18.0	20.0			10.0	9.0
D		20.0			10.0	11.0	6.0
		10.0			10.0	11.0	6.0
		15.0			12.0	13.0	6.0
E		10.0		16.0	14.0		6.5

6 IEEE 802.3av 10Gb/s EPON TF, November 2006

Note 1 – SOA saturation power is measured with a cw source. For a modulated signal with P_{ave} = Psat(3dB), the peak,"1," power will be well into saturation, while the "0" will be below saturation.

Production SOAs operating in the 1490 nm range, as well as SOAs with peak gain > 25 dB are also available on the market.

Alphion
Enabling the photonic future

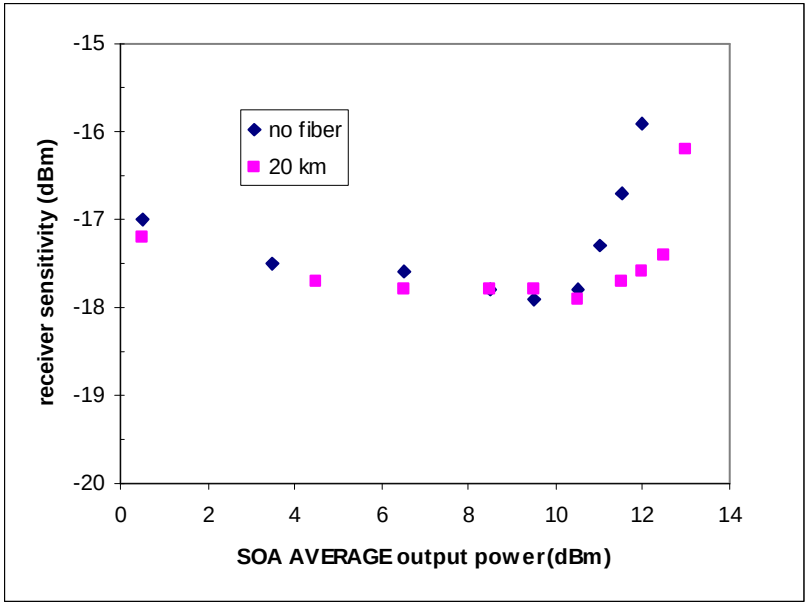
SOA questions

- Performance
  - What happens when SOA operates near saturation?
- State of the art
  - What kind of saturation power are available using present technology?
  - Are there any physical limits to higher saturation powers?
- Feasibility
  - Is SOA technology mature?
  - Are there any lifetime issues when operating SOAs at very high saturation power?
  - What kind of power does such a device draw; what cooling is necessary?

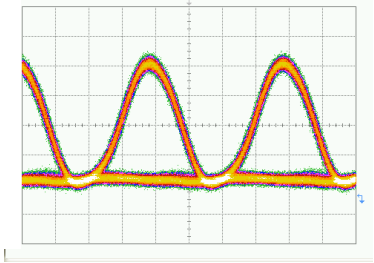
Alphion
Enabling the photonic future

SOAs operating near saturation

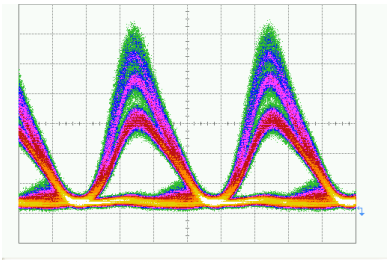
- Near saturation
  - Waveform distortion increases
  - Chirp increases



10 Gb/s RZ signal at 0.5 dB into saturation



10 Gb/s RZ signal at 6.0 dB into saturation



Conditions:

10 Gb/s signal modulation
C-band SOA
P_{sat} (1 dB) = 10 dBm
P_{sat} (3 dB) = 12 dBm
PIN receiver (no optical filter)
~7 GHz electronic filter
Receiver sensitivity measured at 10^{-9} s^{-1} BER

(Note that chirp + dispersion can counteract waveform distortion)

SOAs near saturation

Under the following conditions:

- 10 Gb/s data rate
- Wavelength in the 1480 to 1600 nm range
- Average power at or below the 1 dB (cw) saturation point*
- Through 20 km of G.652 fiber
- Using a PIN receiver

Power penalty will be less than 1 dB compared to operation in the linear regime

*another way to look at this is that the peak power is ~ 4 dB into saturation

Alphion
Enabling the photonic future

SOA state of the art

- Most SOAs marketed today are in-line amplifiers with polarization dependant gain minimized.
  - Since booster amplifiers are matched with a single polarization source, they do not need polarization independent gain.
  - With this constraint removed, higher saturation powers can be obtained.

- Commercially available P_{sat}(1dB) = +10 dBm SOA exist today.

"Semiconductor Optical Amplifiers – High Power Operation" IEEE 802.3av Meeting, Orlando, 13-15 March 2007

SOA hero experiments

"**8×10 Gb/s DWDM transmission over 240 km of standard fiber using a cascade of semiconductor optical amplifiers**," Spiekman, L.H.; Wiesenfeld, J.M.; Gnauck, A.H.; Garrett, L.D.; van den Hoven, G.N.; van Dongen, T.; Sander-Jochem, M.J.H.; Binsma, J.J.M.; Photonics Technology Letters, IEEE Volume 12, Issue 8, Aug. 2000 Page(s):1082 – 1084
(SOAs are operated with P_{ave} at the 1 dB (cw) saturation point with ~ 1dB power penalty)

"**High saturation power (>16.5 dBm) and low noise figure (<6 dB) semiconductor optical amplifier for C-band operation**," Borghesani, A.; Fensom, N.; Scott, A.; Crow, G.; Johnston, L.; King, J.; Rivers, L.; Cole, S.; Perrin, S.; Scrase, D.; Bonfrate, G.; Ellis, A.; Lealman, I.; Crouzel, G.; Chun, L.H.K.; Lupu, A.; Mahe, E.; Maigne, P.; Optical Fiber Communications Conference, 2003. 23-28 March 2003 Page(s):534 - 536 vol.2

"**Record high saturation power (+22 dBm) and low noise figure (5.7 dB) polarization-insensitive SOA module**," Morito, K.; Tanaka, S.; Photonics Technology Letters, IEEE Volume 17, Issue 6, June 2005 Page(s):1298 - 1300

"**An ultrawide-band (120 nm) semiconductor optical amplifier having an extremely-high penalty-free output power of 23 dBm realized with quantum-dot active layers**," Akiyama, T.; Ekawa, M.; Sugawara, M.; Sudo, H.; Kawaguchi, K.; Kuramata, A.; Ebe, H.; Morito, K.; Imai, H.; Arakawa, Y.; Optical Fiber Communication Conference, 2004. Volume 2, 23-27 Feb. 2004

SOA feasibility

- SOAs use the identical InP technology used in
  - 1550 nm DFB lasers
  - EA modulators
  - 1480 nm EDFA pump lasers
    - These devices use similar materials and waveguide dimensions and output > 300 mW (24.8 dBm)
- Fabrication, packaging, and lifetime are well understood.

Alphion
Enabling the photonic future

Powering

- A SOA operating at +12 dBm output power requires:
  - 400 mA of current (with a 1.8 V drop)
  - 3 W of TEC power to operate at 25℃ chip temperature over a case temperature of -40 to 65℃

Alphion
Enabling the photonic future

Physical Limits

- Output power is limited by heating due to the injection of carriers in the active stripe.
- In concept, one could have SOAs with output powers as high as 1480 nm EDFA pump lasers (> 300 mW)
  - In fact Morito, *et al.* demonstrated essentially this in their *Hero* paper.

Alphion
Enabling the photonic future

Summary

- For the 10G – EPON downstream application, SOA-based OLT transmitters can reliably provide required performance with present day technology.

Alphion
Enabling the photonic future