Optoelectronics

A Strategic Study of the Worldwide Semiconductor Optoelectronic Component Industry to 2008

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1. INTRODUCTION

1.1 OVERVIEW

In the years since the second edition of this report the semiconductor optoelectronic component industry has undergone some of the most serious changes in its history. However, during 2004 the market rebounded strongly and although some sectors experienced a slowdown in the final months of the year, which is expected to continue through into the first half of 2005, the industry through to 2008 and beyond is forecast to show strong and sustained growth.

That said it still faces many challenges. Major changes in both technology and marketplace occur as frequently as ever. For this fully revised and updated edition of the report the underlying factors, technologies, usage, applications and marketing strategy of major suppliers, together with competitive market pressures are investigated and overviewed.

The new edition provides market estimates for the base year, 2003, together with a five-year forecast, 2004-2008. New to this edition is an analysis of the business of supplying source materials and wafers to the opto industry including market estimations and a five-year forecast.

All of this is supported by a market analysis, technology trends and profiles of over fifty semiconductor opto component suppliers.

In the past two years further consolidation has occurred in the world opto marketplace. Overall, it is experiencing the effects of global positioning by major corporations. At the same time it has seen the attrition of older names and formation of new start-ups. Companies are stepping up their operations through mergers, acquisitions and investment. Another interesting development is the emergence of China as an important market for the manufacture and use of opto and other components.

It should be noted that this report is mainly concerned with *semiconductor* optoelectronic components, it includes modules and displays and some kinds of non-semiconductor optoelectronic component, e.g. sensors, only where relevant. Nor does it include modules (e.g. transceivers), fibre optics, connectors, displays or electro-optic components. It does, however, provide some coverage of arrays and/or assemblies of devices such as focal plane array detectors and high power diode lasers.

1.2 METHODOLOGY

For the third edition of this report data was gathered from primary and secondary information sources.

A survey was made of opto semiconductor component vendors as well as with a limited number of end-users. These parties were questioned as to present and future business and technical developments within the industry. Much use was also made of the World Wide Web. Although dominated by the US, all suppliers now have their own websites.

Statistics quickly become dated and this is regarded as secondary data which haves been used to formulate trends rather than actual forecasts which have been based entirely on primary sources.

A spreadsheet model of the market was constructed using the primary data obtained from the primary information sources and this was cross-referenced and validated using other data sources and other reports.

Historical data has provided details of market and technology patterns from which it has been possible to forecast future trends within the industry. Notwithstanding the historical input, the forecasts are in part based on subjective estimates from those questioned.

The mathematical model of the market was compiled so as to produce a matrix of forecasts:

- Year-on-year forecasts 2003-2008
- Across geographic regions,
- Across industrial sectors, and
- Types of optoelectronic components.

Finally, it should be pointed out that this report is primarily concerned with "merchant" markets and to a lesser extent "captive". Many optoelectronic suppliers are vertically-integrated supplying internal needs and also selling devices onto the open market.

1.3 GENERAL FORECAST CONSIDERATIONS

With the new decade halfway through, the optoelectronic component industry has begun its return to a period of stronger growth. As such it continues to be very timely to provide an analysis and forecast of this promising market sector.

A number of the major players have already demonstrated their intentions to refocus their businesses. There has been much restructuring but with perhaps most of this completed the market will likely have reached a new level of stability.

Please note that when compiling the figures, statistics etc., tabular information is rounded to one decimal place. Also, it will be noted that main totals may not add exactly; this is due to rounding up/down from sub-total data. All market figures are quoted in US dollar millions.

The following is a list of abbreviations which are used:-

Types of Semiconductor Optoelectronic Component

LED	Light Emitting Diode
LD	Laser Diode
SC	Solar Cell
OC	Optocoupler
DET	Detector
IMG	Image sensors
OTH	Other devices

Application Categories

AUT	Automotive
COM	Computer
CON	Consumer
IND	Industrial
AER	Aerospace and military
COMMS or TEL	Wireless & wirline communications
OTH	Categories not included above

1.4 DESCRIPTION OF REPORT CONTENTS

Chapter One is the **Report Introduction,** which summarises the report methodology and overviews prevailing market conditions.

Chapter Two is the **Executive Summary** of the report with market figures and trends in the industry plus with technological innovations impacting future progress of the industry.

Chapter Three is an overview of the **Applications Markets for Semiconductor Optoelectronic Components**; it describes each market sector, telecoms, computer, automotive, aerospace, consumer and industrial.

The application data are presented for the following industrial groups, namely:

- **Automotive**
- **Computers**
- **Consumer**
- **Industrial**
- **Military & Aerospace**
- **Communications**
- **Others**

A full 5-year forecast and analysis is provided by application and region.

Chapter Four is an overview of the **Market for Semiconductor Optoelectronic Components by Type.**

The forecasts are presented in detail for the following families of opto component:

- **Light Emitting diodes**
- **Laser diodes**
- **Detectors**
- **Solar cells**
- **Image sensors**
- **Optocouplers**
- **Other types**

A full 5-year forecast and analysis is provided.

Chapter Five is an overview of the **Worldwide Optoelectronics Wafer Materials Market**. The forecast includes source materials, plus substrates, epitaxial wafers and epitaxial growth equipment.

Chapter Six provides **Company Profiles of Optoelectronic Component Manufacturers**, from the largest manufacturers to new start-ups likely to have a commercial impact over the next five years.

Chapter Seven is the **Directory of Semiconductor Optoelectronic Component Manufacturers** which includes more than 400 entries, listed in alphabetical order by company name.

Chapter Eight is a range of appendices covering secondary information include:

- Exchange Rates
- Alphabetic List of Acronyms
- Glossary of Terms

- **SECURITY**: Low cost, intelligent sensors and warning lights, etc.
- **INFORMATION:** On-board multimedia data and signalling such as navigation and traffic hazards will require opto components for vehicle-to-vehicle and vehicle-to-roadside communication.
- **ENTERTAINMENT:** Music, video and games are being incorporated in a range of vehicles including buses and cars as well as aircraft.
- **COLLISION AVOIDANCE:** Station keeping and collision avoidance in adverse weather conditions.
- **ISOLATION:** Optocouplers for circuit isolation board-to-board.
- **ENERGY:** Solar cells for recharging equipment.
- **DRIVER AIDS:** There is good potential for low cost image sensors for driver warning etc.

Although new features are normally incorporated on high-end vehicles first and then filter down to higher volume platform as costs are reduced. Legislation is also a key driver in tha adoption of new automotive systems. The mandatory incorporation of CHMSLs in a number of markets has created one of the most important new markets for high brightness LEDs and paved the way for other insertions of this component.

- A subsidiary market is the retro-fitting of units such as CHMSLs to older vehicles for safety and/or customisation.

Application of optoelectronic emitters will further penetrate the general lighting requirements of vehicles, e.g. white light LED units for internal and external illumination, short-term the reversing light and later even the headlights.

Only over the medium to longer term will lasers also become important in this sector. This will be for improved sensing and interconnection in vehicles. Again it will be contingent upon the availability of suitably low-cost, robust devices. VCSELs and low-cost photodiodes could be promising candidates for this forthcoming market.

3.8 INDUSTRIAL MARKETS FOR SEMICONDUCTOR OPTOELECTRONIC COMPONENTS

3.8.1 Summary of Forecast Data

Table 3.10 Industrial Application Market by Region 2003-2008 (US$ million)

	2003	2004	2005	2006	2007	2008
N America	211	259	294	334	409	502
Japan	237	300	336	377	477	604
Europe	101	125	140	156	193	239
Asia Pacific	273	358	393	431	563	739
RoW	43	51	55	60	72	87
Total	865	1093	1218	1358	1714	2171

Table 3.11 Industrial Application Market by Component Type 2003-2008 (US$ million)

	2003	2004	2005	2006	2007	2008
LEDs	280	379	425	477	623	814
Lasers	310	389	433	481	626	817
Det	67	81	90	100	111	123
SC	44	51	57	63	73	85
IS	70	86	95	106	129	157
OICs	56	65	72	80	94	111
Other	37	41	46	51	57	64
Total	865	1093	1218	1358	1714	2171

- Rise in high capacity optical networks.
- Interest in wavelength shift to increase data capacity.
- Better growth in other applications such as sensors.
- Increased penetration of markets once dominated by LEDs.

With all sectors of the laser diode market under price pressure, the price competitiveness of the VCSEL coupled with a performance edge should mean that in due course it could recover.

- Some VCSELs have already matched the unit pricing of some LED types.

Because of this price competitiveness, VCSELs have been mooted as becoming one of the key drivers of the semiconductor optoelectronics market. While this will mostly be via telecoms as these low-cost lasers become better understood by designers they could also begin to compete with other light sources. For example, some industry observers are looking to development of VCSEL-based white light emitters for general illumination. Again, basically this is a substitution of a LED for a VCSEL.

The VCSEL can be a key component in the fibre optic communications sector by providing the highest performance at lower cost in high-speed optical networks. VCSEL technology could also help take the industry into the next generation of computing and communications, including photonic interconnects for board-to-board and chip-to-chip applications. With all-optical out of favour, however, this market potential will likely be for the longer rather than medium term.

For future communications equipment, long wavelength VCSELs could enable greater bandwidth and distance performance in multimode fibre, and lower cost light sources for single-mode fibre applications. Long wavelength VCSELs also provide a path to overcoming eye-safety problems in applications like Parallel Optical Data Links. They will provide the cost and performance benefits of today's short wavelength VCSELs, but offer the additional benefits of transmission in the 1300 nm window.

4.2.7 Trends in High-Power Diode Lasers

In the infra-red laser diodes market, another of the important newer families of devices which has so far not fully realised potential has been high-power diode lasers (HPDLs). The novelty of this family of devices is that for the first time it provides a compact solid-state source of energy rather than relying on the signal processing capabilities of diode lasers.

- HPDL refers to diode laser devices and stacks capable of emitting powers in the region from one watt to as much as a kilowatt and above. They do not refer to diode lasers of intermediate power such as those used in CD or DVD burners.

As a result, in 2003 this market was worth US$140 million having suffered somewhat thanks to the general manufacturing downturn and also the impact of technical problems to do with thermal management. However, it should resume good growth after the 2005 period increasing to US$347 million by 2008, see Tables 4.9 and 4.10.

Table 4.9 Market for High Power Diode Lasers by Region (US$ million)

	2003	2004	2005	2006	2007	2008
N America	36	49	55	57	73	90
Japan	49	66	74	77	98	122
Europe	31	42	47	48	62	76
Asia Pacific	17	23	25	26	34	42
RoW	7	9	11	11	14	17
Total	140	189	212	220	281	347

The substrate market can also be sub-divided into two main customer types:

- There were over 30 captive optoelectronics device production facilities around the world though this number continues to shrink it will remain substantial and be the bigger share of the total market.
- Merchant epiwafer suppliers are also large consumers of substrates and with nearly 20 of such companies worldwide demand is expected to remain substantial though overall less than for captive.

Home to two of the well-established merchant epiwafer houses, Europe's substrate demand is fairly substantial. It is also home to several device manufacturers. But as a whole European substrate demand is expected to not grow quite as strongly as that of North America. However, it will likely increase in terms of owing to demand for this size from key companies such as Osram and IQE.

New fabs have appeared especially in SE Asia notably in Taiwan which contribute to the region's growing appetite for substrates.

- The Japanese share of the overall market has continued to fall over the past few years, due to increased competition from Western suppliers: AXT in the USA, and FCM in Germany, for example. In addition, currency exchange rates have had a negative impact on foreign imports and Japanese exports.

Little progress has been noted for suppliers originating outside the main geographic regions. There are few important suppliers of wafer materials in countries otherwise active in microelectronics such as the Former Soviet Union, S. Korea, Taiwan ROC or PR China or Eastern Europe.

In terms of device production, discrete devices will continue to be the main driver, accounting for over 90% of substrates used today. Discretes will therefore continue to be important for the duration of this report.

5.4.4 GaN and SiC *vs*. Sapphire

The market for the substrates for short wavelength LEDs is split between three basic materials:

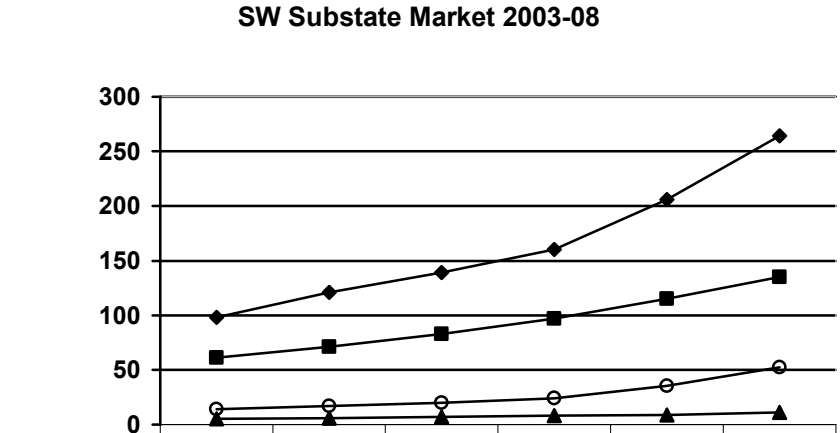
- Sapphire.
- Silicon carbide.
- Others, e.g. gallium nitride.

For the purposes of this context a market estimation of the value of these materials has been made. This forecast is shown in Figure 5.7.

Thus the total market for substrate materials for SW optoelectronics components will grow from US$168 million in 2003 to US$462 million in 2008, an overall CAGR of over 14%. This reflects the substantial growth in numbers of substrates shipped coupled to a progressive fall in unit prices.

After many years of expectations, wide bandgap semiconductors have finally become a very large business. In just over a decade the short wavelength LED, i.e. blue-green, has become a commodity device with many applications. If this could be termed the first wave of commercial success for these materials then a second is already underway with a third in prospect. The application of high brightness GaN/SiC LEDs has permitted the optoelectronics industry for the first time to seriously challenge the traditional lighting industry. The second wave of devices to exploit this technology is the white light emitting LED, thus the market potential for this new family of devices is enormous and worthy of a market report in its own right.

It is currently the industry thinking that violet diode laser optoelectronics will become a higher volume business some time within the next 2-3 years. This will be as a result of the commercial development of digital VCRs, games consoles, and computer data storage based on violet as opposed to today's IR and red lasers.



	2003	2004	2005	2006	2007	2008
Sapphire	98	121	139	160	206	264
SiC	61	71	83	97	115	135
GaN	14	17	20	24	35	52
Other	5	6	7	8	9	11

Figure 5.7 Worldwide Optoelectronics Wafer Materials Market Summary: Substrates for Short Wavelength Devices by Type 2003-2008 (US$ million)

When this market and related business takes off there will be a step function in the demand for substrates and epiwafers. Industry observers suggest that these will be sapphire rather SiC since this is where most of the laser progress has so far been made. Moreover, the devices will be constructed from MOCVD epiwafers and will most likely be mass-produced by large captive Japanese manufacturers such as Sony, Pioneer, Matsushita et al. These have a history in longer wavelength optoelectronics, i.e. IR for CDROM and red for DVD.

Since sapphire substrates are not semi-conducting (they are in fact very highly resistive) they form a special part in this market forecast. That said it cannot be completely ruled out that these violet laser optoelectronics might use other substrates such as SiC or even silicon in due course but at present this looks unlikely. The consensus is that the crystal defect density will be too high for useful optoelectronics to be produced by this method so the present situation will continue for at least another three years.

5.4 The Long-Term Substrate Supplier Situation

To close this section of the materials overview a more speculative forecast is included. Figure 5.8 depicts a general industry trend which shows how the prospects for each substrate diameter product over a decade span. The major points are as follows:

- 2-inch substrates will peak at the mid-point and then decline falling below the large diameter products 7 years in.
- 3-inch substrates are presently the second best performing market but will lose out over the longer term in favour of 4-inch.
- 4-inch could become the preferred replacement as 2-inch operators leap-frog to achieve maximum economic leverage.
- 6-inch is presently at the R&D stage but could become significant towards the end of the decade.

output beam by combining the output of seven individual high-power emitters. The modular CPM-20 provides a bright, reliable optical power source that is ideal for industrial, marking, defence, telecommunications, and medical laser applications. The CPM-20 provides over 20 W of fibre-coupled 915 nm light with exceptional brightness as well as beam uniformity; the output fibre has a 125 µm core with a 0.45 numerical aperture (NA). The rugged and convenient package incorporates the laser sources, fibre combiner and protection circuitry and mounts easily to a system heatsink or chassis. The unit requires a current of 5 A at approximately 15 V, easing power supply selection and hook-up wiring.

- In January 2004 Alfalight announced availability of its ALB1 family of high-power laser diode bars. The company's ALFA laser diode bars provide superior power conversion efficiency and high reliability, as well as low series resistance, high thermal conductivity and high facet damage threshold for all direct diode and diode-pumped solid state (DPSS) laser applications. Alfalight's ALB1 series of standard laser bars offer wavelengths of 808, 915, 940 and 976 nm, with fill factors of 20, 30, 50 and 90%. The ALB1 series bars measure 10 mm long with a 1.0 mm standard cavity length; 1.5 and 2.0 mm cavity lengths were also available. The 808 nm bars have better than 1.1 W/A slope efficiency. Beam divergence is typically 10º x 35º with TM polarization.

- The 14-Pin butterfly packaged, telecom-grade, telcordia-qualified 955 and 976 nm high-power multimode diode lasers with up to 1.5 W output power are suitable for highly reliable cladding pumped EDFAs and CATV amplifiers. The hermetically-sealed, epoxy-free 14-pin package with integrated thermoelectric cooler allows ease of use through user-controlled temperature tuning.

- Alfalight's 808 nm and 976 nm industrial-grade high-power multimode diode lasers with up to 3 W output power are ideal for cladding-pumped EDFAs and DPSS applications. The hermetically-sealed, epoxy-free 14-pin butterfly package with integrated thermoelectric cooler allows ease of use through user-controlled temperature tuning.

Alliances

Alfalight has an agreement with the University of Wisconsin, from whom it licences technology.

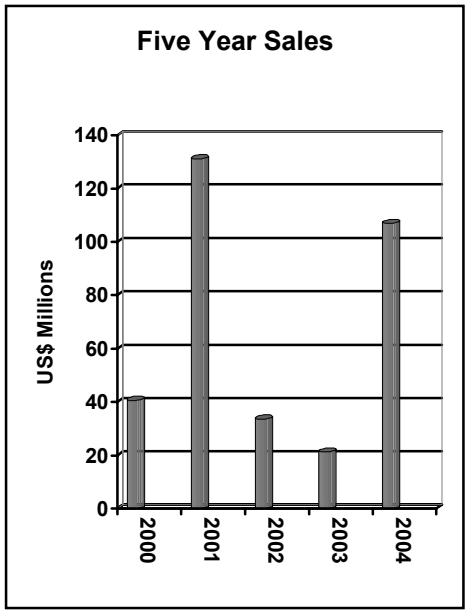
The Company is part of the DARPA Super High Efficiency Diode Sources (SHEDS) program (see *R&D*).

6.5 Avanex

Avanex Corporation
40919 Encyclopedia Circle
Fremont
CA 94538
USA

Founded in 1997 and headquartered in Fremont, CA, USA, Avanex Corporation is a global provider of products for fibre optic communications networks, for applications such as optical wavelength multiplexing, dispersion compensation, switching and routing, transmission, amplification, and network managed subsystems. For FY2004 Avanex reported net revenues of US$106.9 million, an increase of 399% (as a result of its acquisitions) compared to FY2003's figure of US$21.4 million.

During the last two years Avanex has acquired the optical components businesses of Corning and Alcatel Optronics and the optical transmission business of Vitesse in stock transfers:-



- Avanex in July 2003 announced that its stockholders had approved the issuance of Avanex common stock in connection with the acquisition of Alcatel Optronics France SA, and the purchase of certain assets of the photonic technologies business of Corning Incorporated. As consideration for the transactions, Avanex issued to Alcatel and Corning shares of Avanex common stock representing 28% and 17%, respectively, of the outstanding common stock of Avanex on a post-transaction basis. Alcatel and Corning assigned approximately 1,700 patents to Avanex; Alcatel contributed US$110 million in cash to the new company, whilst Corning contributed approximately US$20 million cash. Alcatel also has a three-year supply agreement with Avanex.

- In August 2003 Avanex agreed to acquire substantially all of the assets of Vitesse's Optical Systems Division in exchange for approximately 1.2 million shares of Avanex common stock (valued at approximately US$6 million). Under the terms of the agreement, Avanex has also contracted to buy up to US$2 million in products from Vitesse over three years.

R&D

Research and development expenditure for FY2004 for US$41.7 million, as opposed to US$16.2 million in FY2003.

Facilities

Avanex maintains facilities in the USA at Fremont, CA; Erwin Park, NY (former Corning site); and overseas at Nozay, France (formerly Alcatel); and San Donato, Italy (formerly Corning). The former Alcatel site in Livingston, Scotland (previously FBG and AWG company Kymata, which had been acquired by Alcatel in 2001) was sold to Gemfire Corp, and the Corning Lasertron facility and the Alcatel Lannion plant were discontinued.

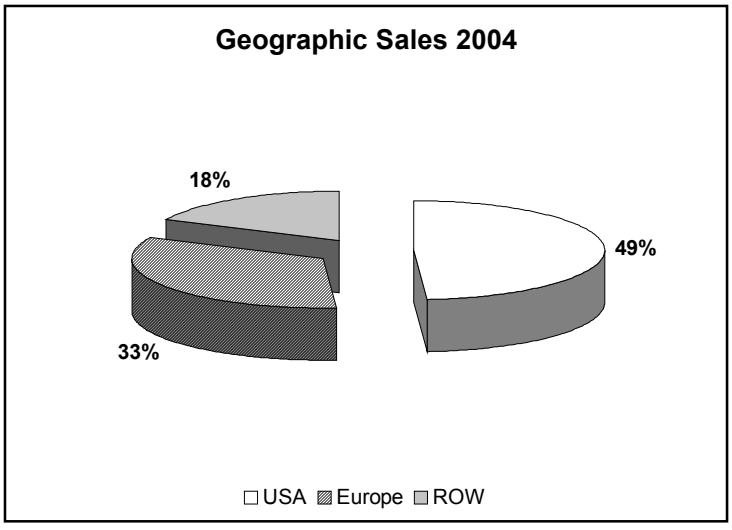
The Nozay plant was the former Alcatel Optronics main facility. It houses the Avanex 'Center of Excellence' in InP and GaAs wafers, lasers, detectors, pump modules, optical interfaces and amplifiers. The facility has a wafer-chip cleanroom and packaging cleanroom.

Products

Avanex offers a range of solutions and technologies for transmission in the 1310 nm and 1550 nm frequency ranges, such as lasers, detectors and modulators. These include:-

- PowerSource™ laser modules, PowerSense™ receiver modules, PowerBit™ and Power™Log $LiNbO_3$ (Lithium Niobate) modulators, PowerReach™ 300 PIN MSA transponders, PowerPort™ XFP transceivers, and PowerFlex™ receivers and transmitters suited to applications at 2.5, 10 and 40 Gb/s. Solutions are available for TDM and DWDM applications at short-reach, intermediate-reach and long- each distances, in a number of MSA form factors and at 1310 and 1550 nm ranges.

- For amplification: PureGain™ fixed-gain and variable-gain Erbium-doped fiber amplifiers and PowerPure™ and PowerDeep™ pump laser modules for terrestrial and submerged applications. Avanex claims its PureGain 2600 Optical Amplifier Series offers the best optical performance in the industry, and the PureGain™, line of amplification solutions continues to be an industry standard-setter, with more than one billion



operational hours in customer networks.

- For dispersion compensation: fixed and tunable dispersion compensation modules in the PowerShaper™ line, and PowerForm™ dispersion compensation modules for single-mode, LEAF(R) and non-zero dispersion- shifted fibre.

- For multiplexing and signal processing: the PowerMux™, PowerFilter™ and PowerBragg™ families of multiplexers and multiplexer modules, interleavers, band separators, channel separators, and gain-flattening filters, all based on either fiber Bragg grating, thin-film filter or Gires-Tournois etalon technology.

- For switching and routing: the PowerExchanger™ Fixed and Power-Balanced OADMs, PowerAttenuator™ Variable Optical Attenuator and PowerFilter™ Passive Network Ready Solution.

PowerPort serial transceivers are XFP MSA-compliant and are available for very short reach (VSR) to long reach (LR2) TDM and DWDM applications. Hot-pluggable for easy application on line cards, they cover spans from 0 to 80 km and they meet ITU-T specifications for SONET/SDH systems.

PowerReach 300 PIN MSA transponders, which offer best-in-class power consumption, are available in both large form factor and small form factor. Large form factor versions provide convenient and flexible optical interfaces for long-reach TDM and DWDM applications up to 3,000 km in SONET/SDH and 10GbE systems. In addition to the full C-Band tunable device, they also are available in single-channel, channel-selectable and laserless versions.

- Avanex announced significant enhancements to its PowerReach™ Full C-Band Tunable Transponder that improve technical performance and provide greater flexibility for system designers. The transponder's receiver sensitivity, at -26dBm EOL, exceeds industry standards, using an innovative PIN with optical pre-amp design. The transponder also offers exceptional optical signal to noise ratio (OSNR) performance and a high dynamic operating range (-26dBm to +4dBm), a critical feature for functions such as system loop-back testing. The PowerReach transponder provides chromatic dispersion performance up to 2000 ps/nm, well beyond the current industry standard of 1600 ps/nm, which allows longer signal transmissions. Output power options range from -4 to 0dBm and +3 to +6dBm; the transponder offers the flexibility of zero or selectable chirp $LiNbO_3$ modulators and multiple C-band tunable laser options.

Small form factor versions cover link spans from 0 to 80 km for short reach (SR1) to long-reach (LR2) TDM and DWDM applications. They are fully compliant to the 300 PIN MSA for 10 Gb/s transponders and meet ITU-T specification for SONET/SDH systems.

In March 2005 Avanex announced that it had started offering foundry services to meet the need for custom optoelectronic components for data communications, telecommunications, medical, defence and instrumentation applications. Avanex has also introduced a set of standard optoelectronics chips with applications in those markets. Avanex's Foundry Services and optoelectronics chips are based on advanced InP, GaAs and Lithium Niobate (LiNbO3) technologies. The standard products include Fabry-Perot (FP) and Distributed Feedback (DFB) laser chips, monolithically integrated Electro-absorption Modulator Laser (EML) chips, pump laser chips and PIN, APD or monitoring photodiode chips.

Alliances

Leading Optical Manufacturers Avanex Corp, Eudyna Devices Inc, Mitsubishi Electric Corp, Oki Electric Industry Co Ltd, Opnext Inc, Sumitomo Electric Industries Ltd, and TriQuint Semiconductor Inc, announced in September 2004 the release of new common specifications for long-reach optical devices based on a 10 Gb/s Miniature Device Multi-Source Agreement (XMD-MSA). The XMD-MSA specifications are designed for applications from short-to-long reach transmission functions.

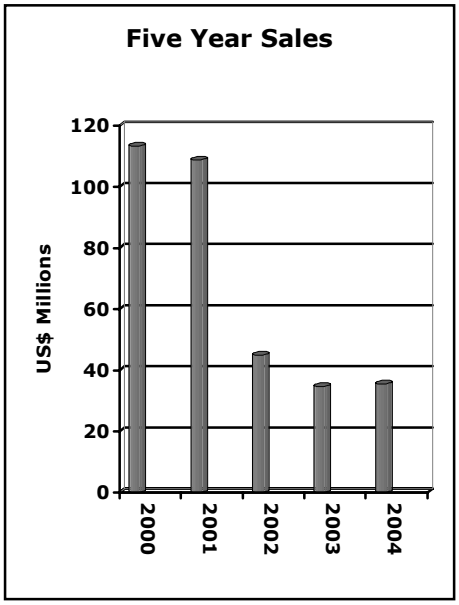
Avanex Financial Highlights - Year-Ending June

US$ millions	2004	2003	2002	2001	2000
Net Sales	106.9	21.4	33.7	131.2	30.7
Net Income/Loss	(124.1)	(102.9)	(77.8)	(119.5)	(38.7)
R&D	41.7	16.2	24.1	37.9	15.6
Total Assets	273.5	154.6	250.4	311.6	278.1

6.6 AXT

American Xtal Technology
4311 Solar Way
Fremont, CA 94538
USA

Substrate manufacturer American Xtal Technology (AXT) was formed in 1986. The Company is a developer and supplier of compound semiconductor substrates such as GaAs, InP and Ge. AXT has a proprietary VGF crystal growth technology for the production of low-defect, semi-insulating and semiconducting GaAs, InP and GE substrates.



The Company reported FY2004 revenues of US$35.5 million, as opposed to 2003's figure of US$34.7 million. The Company has discontinued its optoelectronics production such as LEDs and VCSELs and now concentrates on substrates.

R&D

AXT's research and development expenditure for FY2004 was US$1.5 million, as opposed to US$1.3 million for FY2003. The Company's R&D projects include research into the development of GaN and high purity GaAs epitaxy substrates. It also funds part of its R&D through contracts with the US government and customer-funded research contracts.

AXT holds several patents for its VGF processes.

The Company first began manufacturing VGF grown InP substrates with support from a Small Business Innovation Research (SBIR) program and IR&D.

Facilities

AXT has manufacturing facilities in Fremont, CA, USA, and in Beijing, Xianshee and Nanjing, China.

The Company reduced the workforce at its Fremont, CA, manufacturing facility by 35% (45 people) in June 2004. This was as a result of the company moving manufacturing to its Chinese facility in Xiamen as well as AXT no longer manufacturing optoelectronics devices in the USA

AXT holds ISO 9002 certification.

Products

A direct consequence of the relatively low defect density in VGF grown GaAs substrates is the increased mechanical strength of the material. Substrates with a high dislocation density can easily form microcracks where the dislocations coalesce. High mechanical strength is desirable, because

it results in reduced wafer breakage during volume processing and also allows the use of thin wafers during processing, eliminating the thinning steps often required for devices. The superior mechanical properties of GaAs VGF grown substrates, AXT claims, leads to a unique feature of extra thin 100 µm-thick wafers.

AXT's main product line is GaAs substrates, from 50.8 mm to 150 mm. The Company also produces InP substrates and 100 mm VGF Ge substrates for solar cells in satellites. Ge is used for solar cells because of its close lattice match to GaAs and the greater physical strength of Ge, which permits thinner, lighter wafers.

The Company claims to produce the industry's lowest defect semi-insulating and semiconducting GaAs and InP wafers. The crystals are grown in-house using the VGF process.

Alliances

AXT in June 1999 announced that it has entered into an agreement with Inner Mongolia Mining and Nanjing Germanium to mine germanium in Xilin Gol League, 250 miles from Beijing, China. Inner Mongolia Mining owns the mine property, and Nanjing Germanium is one of China's largest germanium refiners. The agreement, which supplements AXT's source of supply, gives the three partners exclusive rights to the germanium for 25 years. AXT also has the right to purchase refined germanium from the joint venture at competitive prices.

AXT has a supply agreement with Spectrolab Inc for GE substrate, which is used for solar cells for satellites.

Legal Disputes

In December 2004 AXT reached a final settlement of its litigation with Sumitomo Electric Industries Ltd (who filed against AXT in 2003 regarding the infringement of two of Sumitomo's patents), which includes a global intellectual property cross-licensing agreement. AXT recorded a charge of approximately US$1.4 million in the quarter ended September 30, 2004 in connection with this settlement. The agreement requires that payment of this amount be made in early January, 2005 and the litigation in Japan to be withdrawn shortly thereafter.

In March 2004 AXT announced that it had settled all outstanding litigation with Cree and Boston University. Cree and Boston University sued AXT in 2003 alleging that AXT infringed a patent regarding the structure of LEDs held by Boston University and licensed to Cree. AXT countersued for business tort and anti-trust violations. The parties agreed to dismiss all claims and counterclaims.

AXT Financial Highlights - Year-End December

US$ millions	2004	2003	2002	2002	2000
Total Revenue	35.5	34.7	44.9	108.8	113.4
Net Income/(Loss)	(13.6)	(26.7)	(81.2)	(5.0)	21.6
R&D	1.5	1.3	2.3	3.9	4.3
Total Assets	87.5	107.0	145.7	243.4	250.2

7 COMPANY DIRECTORY

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Manufacturer of advanced LED replacements for incandescent lamps

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WS: http://www.alphametals.com
Materials and substrate supplier

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