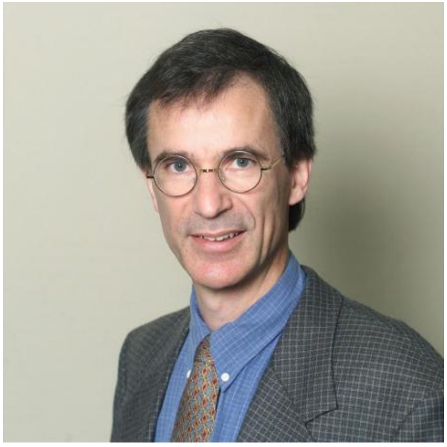
# The Millennium Prize Laureates 2008

*"For their outstanding contributions to telecommunications through the invention and development of the erbium-doped fibre amplifier (EDFA) which enabled the global high-capacity optical fibre network."*



**Professor Emmanuel Desurvire**
Director of the Physics Research Group at Thales Research & Technology, France

**Dr. Randy Giles**
Director of Optical Subsystems and Advanced Photonics at Alcatel-Lucent Bell Labs, USA

**Professor David Payne**
Director, Optoelectronics Research Centre, University of Southampton, UK

## Inventors of the erbium-doped fibre amplifier

There are periods when a technology takes a giant leap forward. This occurred in optical telecommunications between the mid-1980s and 1990s when devices called erbium-doped fibre amplifiers (EDFAs) were born, reached maturity and were put into use in telecommunications networks. They revolutionized telecommunications and are now recognized as vital components in the global optical fibre networks that form the backbone of the information age. The whole of our modern way of life - from business to pleasure, education to entertainment and security to the advancement of human rights - is dependent on optical fibre networks.

Dr. Emmanuel Desurvire, Dr. Randy Giles and Professor David Payne are the creators of the erbium-doped fibre amplifier. Desurvire and Giles worked at the world renown Bell Labs in New Jersey, USA, while Payne worked at Southampton University. These two groups were competitors, spurring each other on and benefiting from each other's work. Professor Payne was first to publish a paper about erbium-doped fibre amplifiers, but Dr. Desurvire and Dr. Giles were first to turn it into a practical tool.

The need for an improved optical amplifier had long been recognized. Before the invention of EDFAs, individual laser signals in fibre cables were boosted electronically by first receiving the signal, transforming it into electronic form and then retransmitting it using a new laser. Not only did this consume significant amounts of power, it was also impractical, restricting expansion in the use of fibres in networks. While a single fibre can carry many laser signals of differing wavelength and polarization, the existing electronic amplifiers could only handle one laser signal at a time. Long distance connections required these amplifiers every 500–600 km to boost the signal levels in the fibre.

Aggressive work was under way on semiconductor optical amplifiers, but because of the constraints imposed by electronic amplification, there was a need for a new concept and approach to optical amplifiers. In the 1960s, one had actually been built by Dr. Elias Snitzer of The State University of New Jersey by incorporating erbium into fibres and then using different methods to excite them to produce signal gain. As his group did not have the required lasers, they used simple flashlights to generate light. The signals employed only lasted milliseconds and as appropriate lasers were not available, the research reached a dead end.

Twenty years later, as lasers had become widely available, many groups around the world were working on optical amplifiers and exploring the addition of different ingredients into fibre to extract more signal gain. In the middle of 1990s significant work that focused on erbium was being carried out at Southampton University in the UK and AT&T Bell Labs in the USA. Bell Labs had built the first fibre laser pumped using a laser diode in 1974 and research had continued. In Southampton, Professor Payne's research group had begun re-examining fibres doped with rare-earths in 1985. A year later, they had their first encouraging results when they managed to operate a room-temperature erbium fibre laser at 1.5 µm. Soon afterwards, they made the first erbium-fibre laser amplifier: a piece of fibre with an erbium additive, a laser source and several optical isolators to control feedback in the amplified light.

"I was trained as a power engineer and my interest was in great big machines with plenty of power," says Payne, who was born in Africa but moved to Southampton at the age of 12. Payne soon found himself at the University of Southampton studying physics. "I became interested in photonics - as it is now called - when I was a young student, and because I also had an engineer's mind, I was able to build one of the world's first fibre-drawing towers."

The Southampton team begun to produce and study communication fibres, and because they made the preforms from which fibres were drawn, "It was relatively easy for us to add erbium - the magic ingredient - to the preforms," says Payne. "Of course we tried many other elements first. The most common laser materials, well known from traditional laser technology, are known as rare-earth elements and there’s a whole range of them including erbium. But only erbium had characteristic gain and absorption at a wavelength of 1.555 microns, which just happens to be the low-loss window for optical fibre. As this is where losses are at a minimum, it’s where all the world’s optical communication systems operate. Erbium turned out to be the perfect choice."

Payne and his group published the first paper revealing the characteristics of optical fibres doped with rare-earth elements in 1985, but Emmanuel Desurvire, a French physicist working at Bell Labs, was already involved in studying these materials. "At the very beginning, fibre optics for me was so-called guided-wave optics, very interesting applications of fundamental concepts in lasers, crystals and fibres. When I joined Bell Labs after conducting experiments at Stanford University, I was immediately fascinated by rare-earth-doped fibres for applications such as laser amplification."

The primary objectives were now practical ones: how to achieve the best possible performance? How much erbium, optimum fibre length, and so on.

Randy Giles, a laser wizard at Bell Labs who had always, as he says, “Liked making optical instruments of one sort of another," joined Desurvire in 1986 in the laser amplifier project and turned it into an industrial development project. "The main difference between the work done in Southampton University and Bell Labs was related to the fact that we're an industrial laboratory,” says Giles. “We immediately made all the tools and resources available to establish what this meant for telecommunications. The fact that real data could be amplified with high quality and high fidelity was something that everybody was anxiously waiting to see proven in a practical situation - or not."

Although the basics were well understood, there was still a practical problem: the big and bulky argon lasers used in laboratories had to be replaced with smaller semiconductor laser diodes, but no diodes powerful enough at the desired wavelength existed. In 1989, the Japanese company NTT came up with a high-gain laser diode that produced light at a suitable 1.48 μm wavelength. "The president of Bell Labs wrote a letter asking whether they could kindly provide us some samples for research, and it worked," recalls Giles, smiling. "The first practical erbium-doped fibre amplifiers soon followed."

## Optical fibre amplifiers

The principle behind the optical fibre amplifier is quite simple: take some optical fibre that incorporates optical material with special properties and, using a laser, target light on it. Optical amplifiers can also be considered to be lasers without the feedback. While a laser’s purpose is to generate coherent light; the optical amplifier boosts the actual quantity of light transmitted.

Physically, optical amplifiers are just a laser source (i.e. a laser diode or an array of laser diodes) and can be regarded as specially-doped optical fibre, reeled into a coil with the optical isolators and filters required to shepherd the light. For scientists the challenge was a threefold one: finding the right doping material, incorporating it into the fibre and constructing a suitable pump laser.

The basic principle behind optical amplification has been known since the era of Albert Einstein. When certain dopant ions in a material are targeted using an intense laser source, their energy state jumps from lower (ground) to higher (excited). The ions spontaneously drop back to ground state by emitting the extra energy as a photon (or light quanta) that corresponds to the energy difference in levels. When the correct energy levels are used, photons emitted by the dopant ions have the same wavelength as the signal light that needs to be amplified. If this signal is input to the medium then the excited ions are forced to release their emery by stimulated emission. The resulting output signal is therefore more powerful than the input signal. Amplification thus results from the stimulated emission of photons from dopant ions in the doped fibre. The dopant ions are maintained in the excited state by a pump laser, which creates an energy reservoir for the amplification process.

Erbium (Er) is a chemical element with an atomic number of 68, making it one of the heaviest elements in the periodic table before the line of radioactive metals. Discovered by Carl Gustaf Mosander in 1843 in Ytterby, Sweden, the salts of this rare earth metal are rose-colored (which is used in artistic glassware). Apart from optical telecommunications, the 1.55 microns laser wavelength of erbium ions is has the "eye-safe" property, which allows many non-hazardous applications such as telemetry, laser imaging, and surgery for skin, eye and ear.

When the core of a silica fibre is doped with trivalent Erbium ions (Er+3) and is efficiently pumped with a laser at either 980 nm or 1480 nm, it exhibits gain in the 1550 nm region. Erbium was perfect for silica-based optical fibre communications, because standard single-mode optical fibres have minimal loss at wavelengths of 1525–1565 nm. Erbium also works very well at 1570-1610 nm, another widely-used transmission window.

The most recent version of the optical amplifier is the Raman amplifier, in which the coil of erbium-doped fibre can be much shorter than in a traditional Erbium amplifier. At 500 mW or more than 1 W of optical power, the pumping power required for Raman amplification is higher than that required by the traditional Erbium amplifiers. The principal advantage of Raman amplification is its ability to provide distributed amplification within the transmission fibre, thereby increasing the spans between amplifier and regeneration sites.

## Applications

The first commercial use of erbium-doped fibre amplifiers was in underwater communication cables, where the advantages offered by optical amplification of the laser signal are considerable. The amplifiers are located inside torpedo-like repeaters placed in the cable at distances of 500-800 km. Modern systems also permit wavelength-division and polarization multiplexing, which dramatically increases the fibre's transmission capacity.

Communications satellites lost most of the North Atlantic telephone traffic they carried to these low-cost, high-capacity cables. The slump in the communication satellite markets and commercial launcher business in the 1990s was largely a result of the introduction of erbium-doped fibre amplifiers and the huge increase in cable bandwidth they made possible.

Nowadays, optical amplifiers are widely used in all kinds of optical networks – both terrestrial and underwater. Their importance is increasing as optical cables gradually replace the older copper cables and domestic use expands. The smallest amplifiers are no bigger than a matchbox, while the underwater repeaters are several meters long.

Optical amplifiers are used also in industries where high-power lasers are used for cutting, marking and machining, and amplifiers are widely used in surgical lasers.

While optical amplifiers are now produced all over the world, only a few companies manufacture erbium-doped optical fibre. SPI Lasers, co-founded by Professor Payne, is one of these companies and also a leader in the manufacture of industrial and surgical lasers.

## Potential applications in the future

The most obvious future use for optical amplifiers lies in the exponential demand for high-speed Internet connectivity and the booming demand for greater communications capacity.

Industrial applications are also increasing steadily as the power of the laser beams available increases. While lasers are of course used in heavy industry, they also enable many smaller businesses with to offer highly personalized services and allow small production series or special orders to be produced in an economic way.

New kinds of optical amplifiers will be needed when quantum computers and their associated optical systems arrive.

## Payne, Giles and Desurvire today

David Payne is currently a director of the Optoelectronics Research Centre (ORC) at the University of Southampton in the UK. One of the world's leading institutes for photonics research, ORC will be moving into a brand new building in the near future to replace an earlier lab that was destroyed by fire some years ago. Professor Payne reveals his engineering inclinations by driving a BMW M3 sports car and his Harley Davidson motorcycle, and at home, his favourite place is kitchen. "Yes, I like cooking and good food. By the way, do you know a chef called Heston Blumenthal? He makes wonderful experimental food called molecular gastronomy."

Randy Giles continues to work at Bell Labs, now part of Alcatel-Lucent, and has achieved many advances in laser technology - including the first practical optical switch. One of his current projects is an ultra-small projector based on three small laser diodes. For relaxation, he climbs mountains or can be found running on Murray Hill, New Jersey, where his office and laboratory are located.

Emmanuel Desurvire has returned to France and is working as the head of Thales' physics research unit in Palaiseau near Paris. "Research people are very hard to manage in a conventional sense, but I think I'm quite good at it, because I was once one of them. It's very exciting to be in a position where I can inspire and motivate new generations of researchers." As well as being a prolific writer, his home-based activities include playing classical guitar and carpentry - guitars included.

## Further reading

http://en.wikipedia.org/wiki/Optical_amplifier
http://en.wikipedia.org/wiki/Optical_fibre
http://www.alcatel-lucent.com/bell-labs
http://www1.alcatel-lucent.com/submarine/
http://www.thalesgroup.com/
http://en.wikipedia.org/wiki/David_Payne
http://www.orc.soton.ac.uk/

Emmanuel Desurvire: Erbium-Doped Fiber Amplifiers, Principles and Applications (ISBN-13: 978-0471264347); Wiley-Interscience; New Ed edition (August 19, 2002)

Emmanuel Desurvire: Erbium-Doped Fiber Amplifiers, Device and System Developments (ISBN-13: 978-0471419037); Wiley-Interscience; Subsequent edition (August 8, 2002)

## CV - Professor Emmanuel DESURVIRE

French Citizen
Born 1955 in Boulogne, near Paris, France
Married

| | |
|---|---|
| 1974 | Baccalauréat, Lycée Claude Bernard, Paris |
| 1977 | B.S. in Physics, Paris VI University |
| 1980 | M.S. in Physics, Paris VI University |
| 1981 | M.S. (DEA) in Theoretical Physics, Paris VI University |
| 1981 - 1983 | Ph.D. Student, Thomson-CSF (now Thales) Central Research Facility Corbeville, Orsay, France |
| 1983 | Ph.D. in Applied Physics, University of Nice |
| 1984 - 1986 | Postdoctoral Research Affiliate, Applied Physics Department, E. L. Ginzton Laboratory, Stanford University, USA |
| 1986 - 1990 | Member of Technical Staff, AT&T Bell Laboratories, Crawford Hill Laboratory, New Jersey, USA |
| 1998 | Sc.D. (HDR Thesis), University of Nice |
| 1990 - 1993 | Associate Professor, EE Department of Columbia University, New York, USA |
| 1994 - 1998 | Group Leader, Undersea Transmission, Alcatel-Alsthom (later Alcatel-CIT) Research, Marcoussis, France |
| 1998 - 1999 | Deputy Unit Director, Photonics Networks Unit, Alcatel-CIT, Marcoussis, France |
| 1999 - 2000 | R&D Project Manager |
| 2000 - 2004 | Director, Alcatel Technical Academy |
| 2004 - 2006 | Director, Alcatel, Corporate Intellectual Property Group |
| 2006 - 2007 | Senior Director, Alcatel Optical Networks Division |
| 2007 - | Director, Thales Research & Technology, Physics Research Group |

**Notable prizes and awards**

| | |
|---|---|
| 1992-93 | Distinguished Lecturer Award, Lasers and Electro-Optics Society (IEEE) |
| 1984 | International Prize In Optics , International Commission for Optics (ICO) |
| 1998 | Benjamin Franklin Medal In Engineering, Benjamin Franklin Institute |
| 1998 | Grand Prize in Electronics of Gai A.Ferrée, Federation des Anciens des Transmissions |
| 2000 | IEEE Fellow, Institute of Electrical and Electronics Engineers (IEEE) |
| 2001 | Distinguished member of Technical Staff, Alcatel Technical Academy |
| 2004 | Alcatel Fellow, Alcatel Technical Academy |
| 2005 | William Strelfer Scientific Achievement Award, Lasers and Electro-Optics Society (IEEE/LEOS) |
| 2006 | Thomson Scientific Laureate, Thomson Scientific |
| 2007 | John Tyndall Award, Optical Society of America and Lasers & Electro-Optics Society (OSA/LEOS) |
| 2007 | Prix France-Telecom, France's Academy of Sciences |

**Patents and publications**

210 publications (98 Journal, 104 conference, 8 book chapters)
Author of five books (publications 1994,2003,2004 and 2008)
113 patents in 34 patent families

## CV - Dr. Randy GILES

Citizen of the USA and Canada
Married

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|---|---|
| 1976 | BSc in Physics, University of Victoria, Canada |
| 1978 | MSc in Physics, University of Victoria, Canada, 1978 |
| 1983 | PhD in Electrical Engineering, University of Alberta, Canada |
| 1983 -1986 | Member of Scientific Staff at Bell Northern Research in Ottawa, Canada |
| 1986 - 1999 | Member of Technical Staff at Bell Laboratories |
| 1999 - 2001 | Technical Manager at Bell Laboratories |
| 2000 - | Director, Optical Networks at Bell Laboratories |
| 2001 | Director of Photonic Subsystems Research at Bell Laboratories |
| 2001 - 2006 | Director of Advanced Photonics Research at Bell Laboratories |

**Notable prizes and awards**

| | |
|---|---|
| 2000 | Discover Magazine Technology Award |
| 2000 | Named, Fellow of the Optical Society of America |
| 2001 | Bell Laboratories President's Gold Award |
| 2001 | Named, Fellow of Bell Laboratories |
| 2005 | Fraunhofer Award/Burley Prize from the Optical Society of America |

**Patents and publications**

Author or co-author in more than 100 publications/conference papers.
Has 50+ patents filed and more than 30 patents awarded.

## CV - Professor David PAYNE

British Citizen
Born 13 August 1944
Married

| | |
|---|---|
| 1949-1963 | Primary and Secondary Education in Central Africa (Zambia) |
| 1964-1967 | B.Sc. Honours, Electrical Engineering, University of Southampton, UK |
| 1967-1968 | Diploma in Quantum Electronics, University of Southampton, UK |
| 1969-1976 | PhD degree, University of Southampton, UK (Part time Registration) |
| 1969-1971 | Research Assistant, Dept. of Electronics, University of Southampton |
| 1971-1972 | Junior Research Fellow, Dept. of Electronics, University of Southampton |
| 1972 | Pirelli Research Fellow, University of Southampton, UK |
| 1974 | Optical Communications Group Leader, University of Southampton |
| 1978 | Senior Research Fellow, University of Southampton, UK |
| 1981 | Principal Research Fellow, University of Southampton, UK |
| 1984 | Reader, University of Southampton, UK |
| 1989 | Deputy Director, Optoelectronics Research Centre, University of Southampton, UK |
| 1991 | Professor of Photonics, University of Southampton, UK |
| 1995 - | Director, Optoelectronics Research Centre, University of Southampton, UK |

### Commercial activity

| | |
|---|---|
| 1981 - 1991 | Co-founder and Director, York Technology Ltd. (now PK Technology Inc.), UK |
| 1991 - 2000 | Founding Consultant, Sensor Dynamics, UK (now part of SENSA) |
| 1987 - 1990 | Consultant, Amoco Technology, Naperville, USA |
| 1995 - 2000 | Consultant, Scientific Atlanta (ATx), Naperville, USA |
| 1998 - | Co-founder, Director and Chairman, Southampton Photonics Inc. |
| 1999 - 2001 | Director, Geosensor, USA |

### Notable prizes and awards

| | |
|---|---|
| 1982 | Academic Enterprise Award for establishing York Technology |
| 1986 | Queens Award for Industry (York Technology) |
| 1991 | IEEE/OSA John Tyndall Award (USA) |
| 1991 | Rank Prize for Optics (UK) |
| 1992 | Elected Fellow of the Royal Society |
| 1993 | Computers and Communications Award (Japan) |
| 1994 | MASTS (USA) Real Advances in Materials Award |
| 1896 | Elected Fellow of the Optical Society of America |
| 1997 | One of 12 scientists included in the Optical Society of America's time capsule due to be opened in 2016 |
| 1998 | Benjamin Franklin Medal in Engineering-Franklin Institute USA |
| 1998 | Elected to the Royal Society of Arts |
| 2000 | ISI Certificate for one of the world's most-cited authors |
| 2001 | 2001 Basic Research Award of the Eduard Rhein Foundation |
| 2001 | Ernst and Young Entrepreneur of the Year finalist |
| 2001 | Mountbatten Medal of the IEE for outstanding contributions to |

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| | electronics |
| 2002 | ISI Certificate for Highly Cited Researchers - original member |
| 2003 | LEOS (USA) Distinguished Speaker |
| 2003 | IEE Distinguished Speaker |
| 2004 | Appointed Commander of the British Empire (CBE) |
| 2004 | Elected to the Norwegian Academy of Sciences |
| 2004 | Kelvin Medal of the 8 major UK engineering institutions |
| 2005 | Elected Fellow of the IEE |
| 2005 | Elected Fellow of the Royal Academy of Engineering |
| 2005 | Royal Academy of Engineering MacRobert Award finalist (SPI Lasers) |
| 2007 | Elected to the Russian Academy of Sciences |
| 2007 | IEEE Photonics Award for outstanding achievements in photonics |

**Patents and publications**

Author and co-author of more than 600 journal/conference publications.
Inventor and co-inventor in more than 20 patents and patent applications