2003

FROST & SULLIVAN

MICROFLUIDICS IN PHOTONICS
EXCELLENCE IN RESEARCH

Presented to

BELL LABS

CHAIRMAN

Founded in 1961, Frost & Sullivan is recognized as a global leader in growth consulting. Frost & Sullivan Awards are presented to companies that demonstrate excellence in their industry, commending the diligence, commitment, and innovative business strategies required to advance in the global marketplace. Frost & Sullivan rigorously analyzes specific criteria to determine award recipients in a vast variety of market industries and landscapes.

2003 Excellence in Research - Microfluidics in Photonics
Award Recipient: Bell Labs

Award Description

The Technical Insights' Excellence in Research of the Year Award is bestowed upon the company that has carried out new 'disruptive' research; and has, in general, a strong commitment to research and development. This award recognizes a company's research and development program that has or is expected to bring significant contributions to the industry in terms of adoption, change, and competitive posture. The fruits of this research may already have or will potentially impact certain market sectors. The award also recognizes the overall research excellence of a company as well as its commitment towards differentiating itself based on science-backed services or solutions.

Research Methodology

To choose the award recipient, the Technical Insights' analyst team tracks research and innovation in key hi-tech markets. The selection process includes primary participant interviews and extensive primary and secondary research via the bottom-up approach. The analyst team shortlists candidates won the basis of a set of qualitative and quantitative measurements. The analyst also considers the pace of research and technology innovation and the significance or potential relevance of the research to the overall industry. The ultimate award recipient is chosen after a thorough evaluation of this research.

Measurement Criteria

In addition of the methodology described above, there are specific criteria used to determine the final rankings. The recipient of this award has excelled based on one or more of the following criteria:

- Number or type of research projects
- Significance of research in the industry, and across industries (if applicable)
- Absolute R&D expenditures (vis-a-vis industry norm), and % growth (if applicable)
- Caliber/reputation of research staff
- Potential of products of research to become industry standard(s)
- Breadth of intellectual property ownership (patents, scientific publications, papers in peer reviewed journals, etc)

Award Recipient: Bell Labs

The winner of the Technical Insights' Excellence in Research Award for 2003 is Bell Labs of Murray Hill, N.J., for its work on developing new vistas for applications of microfluidics in the field of photonics. Currently, optical fiber performs a predominantly passive role in a network by transmitting light from one place to another. Over the past few years, Bell researchers, led by John Rogers, nanotechnology research director, have incorporated interior microchannels into optical fibers through which plugs can be pumped to where they are needed to adjust the fiber's optical properties. This enables scientists to dynamically tune the properties of optical fiber and, in general, other types of integrated optical components, such as planar waveguides and modulators.

The research is significant because it represents a completely new direction for photonics, which enables devices with functionality that is impossible to achieve with other approaches. By moving fluids around, one can induce extremely large effective changes in optical properties, which are orders of magnitude larger than those possible by using the standard approaches of thermal, strain or electro-optic tuning. Because the fluids flow and conform to complex surfaces, they are inherently compatible with a wide range of optical structures, from fibers to planar waveguides to various microoptical elements such as photonic crystals. Bell Labs believes that this type of technology will play important and complementary roles to conventional devices in future networking systems.

The optical devices that the Bell researchers have demonstrated using microfluidices include tunable - in both attenuation depth and wavelength - narrow band filters that are important for their ability to perform dynamic gain equalization in metro and long haul WDM networks. They also demonstrated switchable broadband attenuators, with contrast ratios of more than 40 dB. These devices can be used as on/off shutters or grey scale filters for use in many different areas of optical networking. The Bell research team has developed two versions of this device: one that uses pumped simple fluids (index control) and one that uses pumped mixtures of polymer/liquid crystal (scattering control). They are focusing on the development of these devices for use in optical channel monitor (OCM) systems.

To make their polarization controllers, the Bell Labs researchers are exploiting liquid crystals, which are fluids that can be pumped to various locations along the fiber, and also which can be electro-optically tuned. They have demonstrated controllers that offer speeds of 1 degree/microsecond that are suitable for use in polarization mode dispersion compensators. They have demonstrated these devices in 40Gb/s testbed networks. In addition, the Bell microfluidics researchers have demonstrated polarimeters that can measure the state of polarization, also with microsecond speeds. This class of device also uses liquid crystals and has been demonstrated in 40Gb/s testbeds.

In addition to the planar microfluidic geometry, there are the two other new pieces of technology that Bell Labs has introduced in the past three months. First is the use of electrowetting, as a purely solid-state, non-mechanical way to pump fluids around in these networks in a very power efficient way and at high speeds. Second is the use of liquid crystals and polymer dispersed liquid crystals for microfluids that can not only be pumped but also can be tuned electrically.

In sum, Bell Labs is the recipient of the 2003 Technical Insights' Award for Excellence in Research for using microfluidics to open a unique direction for photonics research; one that is bringng tangible products to the market and one with immense potential for future growth. This will enable scientists to dynamically tune the properties of optical fiber and other types of integrated optical components, including planar waveguides and modulators, to extend the capabilities of optical networks.

The Bell research team has several patent applications in microfluidics, and also published seven papers in peer-reviewed scientific journals. The most recent ones include:

- B.R. Acharya, C. Madsen, L. Moller, K.W. Baldwin, R.A. MacHarrie, C.C. Huang, R. Pindak and J.A. Rogers, "In-Line Liquid Crystal Microcell Polarimeters With Applications in 40 Gb/s Systems," *Optics Letters*, in press.

- J. Hsieh, P. Mach, F. Cattaneo, S. Yang, T. Krupenkine, K. Baldwin and J.A. Rogers, "Tunable Microfluidic Optical Fiber Devices Based on Molded Plastic Microchannels and Electrowetting Pumps," *IEEE Photonics Technology Letters*, 15(1), 81-83 (2003).

- B.R. Acharya, K.W. Baldwin, R.A. MacHarrie, C.C. Huang, R. Pindak and J.A. Rogers, "High Speed In-Fiber Nematic Liquid Crystal Optical Modulator Based on In-Plane Switching," *Applied Physics Letters*, 81(27), 5243-5245 (2002).

- P. Mach, C. Kerbage, A. Hale, R.S. Windeler, B.J. Eggleton, J.A. Rogers, "Optical Fiber Devices Whose Transmission Characteristics are Controlled by Scattering," *Applied Optics*, 47(33) 7018-7023 (2002).

- P. Mach, T. Krupenkin, S. Yang, J.A. Rogers, "Dynamic Tuning of Optical Waveguides with Electrowetting Pumps and Recirculating Fluid Channels," *Applied Physics Letters* 81(2), 202-204 (2002).

- C. Kerbage, R. Windeler, B.J. Eggleton, P. Mach, M. Dolinski and J.A. Rogers, "Tunable Devices Based on Dynamic Positioning of Micro-Fluids in Microstructured Optical Fiber," *Optics Communications*, 204(1-6), 179-184 (2002).

- P. Mach, C. Kerbage, M. Dolinski, K.W. Baldwin, R.S. Windeler, B.J. Eggleton, J.A. Rogers, "Tunable Microfluidic Optical Fiber," *Applied Physics Letters* 80(23), 4294-4296 (2002).