

The 2001 OFC conference, at the peak of the bubble, attracted nearly 38,000 attendees, breaking all previous attendance records.

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OSA Centennial Snapshots

Boom, Bubble, Bust: The Fiber Optic Mania

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In the decade from 1996 to 2005, breakthroughs in fiber optics and networking transformed society and laid the groundwork for the global internet. The same decade showed how technological breakthroughs could bring economic turmoil.



The development of erbium-doped fiber amplifiers, by OSA Fellow David Payne and others, helped kickstart the fiber optic boom.

ORC/University of Southampton

Fiber optic technology boomed in the decade from 1976 to 1986, going from cautious field trials of custom-built hardware to the backbone of the terrestrial telephone network within a decade. But that was only a small-scale preview of the tumultuous decade from 1996 to 2005, when dramatic advances in fiber optic technology created a business boom that became a bubble that burst with losses in the trillion-dollar range.

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Driving the boom and bust was a perfect storm of rapid advances in three closely related technologies: fiber optic capacity, the power of personal computers and networking software. The result was a technological breakthrough that brought the explosive growth of the internet—and an air of irrational exuberance that brought economic tumult.

Disruptive technology

The seeds of the technological revolution were sown in the 1960s, when both information-service networks and fiber optic communications were proposed. Information services were first demonstrated over telephone wires in the 1970s, along with fiber optic phone lines and a pioneering Japanese demonstration that delivered video as well as data over optical fibers to homes in Higashi-Ikoma, Japan.

Commercial information services emerged in the 1980s and soon were linked to a new generation of personal computers using dial-up modems. Meanwhile, single-mode fiber transmitting hundreds of megabits per second became the digital backbone of the global telecommunication network on land and at sea. The telecommunications company Sprint boasted that callers could “hear a pin drop” on its fiber optic phone network. Deregulation opened telephone markets in many countries.

Early fiber optic links were hobbled by the need for electronic signal amplification every 30 to 50 kilometers. David Payne’s invention of the erbium-doped fiber amplifier at the University of Southampton, U.K., in 1986 opened the door to practical optical amplification in the 1550-nm band, where glass is most transparent.

Optical amplification was an important advance for transmitting a single signal, but it was a breakthrough for wavelength-division multiplexing (WDM) of many signals on a fiber. WDM began with a series of advances, many reported at the annual Optical Fiber Communication (OFC) conference. Erbium-doped fibers demonstrated gain of at least 10 decibels across a 25-nm band. Signals could be transmitted through a fiber at separate wavelengths without significant crosstalk. New optics began dividing the erbium gain spectrum into thinner and thinner slices, allowing more and more optical signals to be sent through a single fiber.

Telecommunications capacity had long been limited by bandwidth. WDM broke the bandwidth bottleneck by multiplying fiber capacity. Will Hicks, a fiber optic pioneer in the 1950s and serial entrepreneur, was quick to realize the huge capacity of WDM systems. Business writer George Gilder picked up the idea from Hicks, and Gilder's praise of fiber in the first issue of the magazine *Forbes ASAP* in 1992 caught the eye of investors. Soon he was predicting fiber would make bandwidth "virtually free."

"I was just fascinated by that article, and tried to digest what was happening," recalls Kevin Kimberlin, an investor and cofounder of Ciena. He visited Optelecom, a fiber company founded in the 1970s by Gordon Gould and William Culver, where physicist David Huber showed him how WDM could send two movies through the same fiber without crosstalk. Huber said a single fiber could carry 100,000 television channels, maybe as much as a million. Optelecom wasn't interested, but Kimberlin and Huber launched the company that became Ciena in April 1993. It was just weeks after release of Mosaic, the first widely used web



Ciena's CN 2150 passive optical multiplexer, a later generation of the MultiWave 1600, which in 1996 increased Sprint's network capacity by 1,600 percent. © Spencer Trask/Julie Allocco

browser—an advance that made the internet easy, and increased the need for bandwidth.

Big bandwidth at OFC

Pirelli launched the first WDM systems with four channels spaced fairly widely across the erbium-amplifier band in 1994. Ciena was the first to offer dense WDM (DWDM) in a system with 16 channels spaced at 1.6-nm (about 200 GHz) intervals, at the 1996 OFC in San Jose, Calif. With each channel carrying the then-standard 2.5 gigabits per second (Gbit/s), one fiber pair could carry 40 Gbit/s. It was a highlight of the show, which had grown from 3,649 attendees in Atlanta in 1986 to 6,584 in San Jose a decade later.

The 1996 OFC postdeadline session heard H. Onaka of Fujitsu report sending a record 1.1 terabits per second through 150 km of single-mode fiber. His group sent 20 Gbit/s on each of 55 channels spaced 0.6 nm (75 GHz) apart in a testbed including four erbium amplifiers and three lengths of dispersion-compensating fiber.

With web traffic soaring, Ciena in June 1996 found its first customer,

Sprint, owner of the third-largest long-haul phone network in the United States. Sprint paid nearly US\$200 million to upgrade previously installed fibers to carry 16 wavelengths. To Kimberlin, that first commercial DWDM system was "the real dawn of the internet." It was also a milestone showing that technology barely beyond the laboratory stage could be put to work helping real-world networks keep up with the rapid growth of web traffic.

DWDM developers still faced daunting challenges. They needed to level gain across the erbium band to amplify all wavelengths evenly. They needed to compensate for dispersion to prevent pulse spreading. And they needed to engineer DWDM optics to reduce losses and slice the spectrum into more and thinner channels. But engineers soon solved those problems.

Company stocks soared with fiber performance and market demand for more capacity. Ciena's market capitalization reached US\$3.4 billion when it went public in February 1997. In the 7 April issue of *Forbes*, Gilder predicted "the total bandwidth of communications systems will triple every year for the next 25 years," creating trillions of dollars in new wealth.

By the time of the February 1999 OFC in San Diego, Calif., the technology-rich NASDAQ stock average was in the 2300s, heady new territory. OFC itself had grown to a record 10,206 attendees, with exhibit space double that of 1996. In a plenary talk, Jack Wimmer of MCI Worldcom declared: "The challenge now is to take [DWDM] technology out of the lab, ensure that it is scalable and robust, and deploy it into the network at the earliest possible date." He envisioned "hundreds of wavelengths, [each] with time-division multiplexed bit rates reaching 40 gigabits per second."

The optics world had never seen the likes of the March 2001 OFC before and may never see it again.

Wimmer's vision was well beyond the record three terabits per second through 40 km of fiber that Nippon Telegraph and Telephone reported at the postdeadline session. NTT used 19 channels, each transmitting at 160 Gbit/s, spaced 480 GHz (about 4 nm) apart, from 1540 to 1609 nm. Ciena had offered 96 DWDM channels in a commercial system in 1998, but with each wavelength capable of 2.5 Gbit/s, so the total capacity was 240 Gbit/s, more than an order of magnitude short of the NTT report. Nobody seemed to notice that no one outside a laboratory had lit so many wavelengths, and no single route needed all that capacity.

The bubble year

Gilder was the opening plenary speaker at OFC 2000 on 7 March in Baltimore, Md. The NASDAQ average reached 5000 for the first time that day, and closed the week at 5048.62. A crowd of 16,934 overwhelmed the registration staff and wrapped twice around the convention center. The show covered 121,000 square feet. It was a magical manic moment.

Giant optical switches and tunable lasers for WDM were hot. In the postdeadline session, Bell Labs described a 112x112-element micromirror device that, on paper, could switch 35.8 terabits per second, which the parent Lucent Technologies planned to market. After the show, arch-competitor Nortel spent US\$3.25 billion to buy Xros,

a startup with similar technology it said could be scaled to 1,152 ports. Two weeks after OFC, Nortel paid US\$1.43 billion for CorTek, a startup which had described a micromirror-tunable optically pumped VCSEL for WDM systems at the postdeadline session.

Dazzled by the new technology, investors were throwing money at anything optical and innovative. Easy money helped startups multiply. Everybody seemed to be hiring. Fiber optic technology was on a roll, and promised a huge new optical market that could sustain long-term growth.

The NASDAQ slipped below 5000 after OFC, as the first round of companies began to fail in what would later be called the "dot-com bust." But investors shifted their bets to telecommunications and optics, and those stocks held their gains. On 10 July 2000, JDS Uniphase announced it would buy SDL Inc. for US\$41 billion in stock, the biggest deal ever in optics. During the summer, JDSU's market capitalization reached US\$181 billion. Order books were full and construction crews were laying new fiber optic cables as fast as the fiber could be drawn.

The stratospheric prices made Kimberlin uneasy. "You know when there's a mania, and say this can't continue," he recalls. He thought Ciena was solid, but when its market capitalization hit US\$30 billion, he decided that was good enough, and started cashing out. Most others just let the good times roll.

OSA Centennial Timeline 1996-2005

www.osa.org/100

OSA
HISTORY

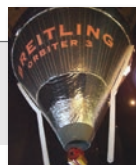


1997
OSA Launches Its First All-Electronic
Publication, *Optics Express*



2000
Optics InfoBase
Goes Live

POLITICAL/
SOCIAL



1999
Piccard and Jones Circumnavigate
the Globe in a Hot Air Balloon



2001
Apple Computer
Launches the iPod

SCIENCE/
ENGINEERING

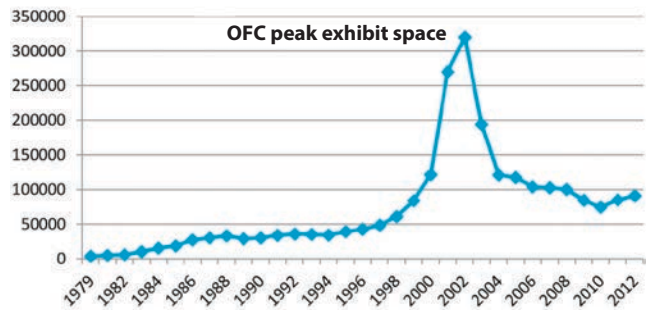
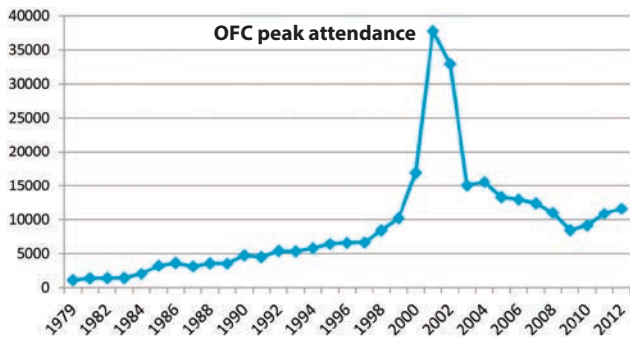


1996
Dolly the Sheep is Born, the
First Cloned Mammal



1997
NASA's Pathfinder
Probe Lands on Mars

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Attendance and exhibit space skyrocket

At the Optical Fiber Communications (OFC) conference, total attendance (left) and exhibit space (right) both exploded during the 2001-2003 bubble and bust.

The biggest optics show ever

The optics world had never seen the likes of the March 2001 OFC before and may never see it again. The convention center in Anaheim, Calif., offered the needed space, and Disneyland across the street added a dash of fantasy. Total attendance more than doubled to 37,806, with a record 10,888 technical attendees, 975 exhibitors and 270,000 square feet of exhibits.

The day before the show, John Dexheimer of Lightwave Advisors reflected on the past year's mania at an OSA Executive Forum at the Disneyland Hotel titled "Feeding the Beast." He warned of potential problems: US\$250 billion in junk bonds to finance new fiber builds, and vendor financing that had brought Lucent close to default. He said write-downs were coming in optics and that too many companies were trying to do the same thing. Yet he expected that the fiber industry's big challenge would be meeting rising demand.

The exhibits featured optimism, startups, and many people new to optics. The job market was booming. Companies were starting to show systems transmitting 10 Gbit/s, an important step up from 2.5 Gbit/s.

Impressive new technology highlighted the postdeadline sessions. Kiyoshi Fukuchi of the NEC Computer and Communication Media Research Center in Kawasaki reported a record fiber data rate of 10.92 terabits per second. It was a big jump from the 3 Tbit/s record of two years earlier, but there were issues. The 40-Gbit/s signals at 273 wavelengths from 1476 to 1610 nm spanned only 117 km of fiber, and dispersion posed a roadblock to sending 40-Gbit/s signals much longer distances. Yet 10-Gbit/s systems looked good, and attendees left tired but happy.

Over the cliff

Behind the scenes, however, the picture was darker. Component sales were dropping like a rock. In April, JDSU cut 5,000



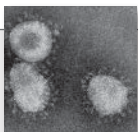
2001
Anthony M. Johnson Becomes OSA's
First African-American President



2003
OSA Co-Publishes (with Elsevier)
The Science of Color, 2nd Ed.



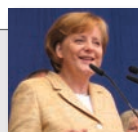
2004
Peter L. Knight Becomes OSA's
First European President



2003
SARS Virus
Spreads



2004
Facebook Launches;
Google IPO



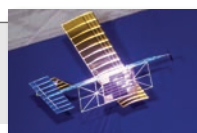
2005
Angela Merkel Sworn in as
Germany's First Female Chancellor



1999
The First Blackberry
Hits the Market



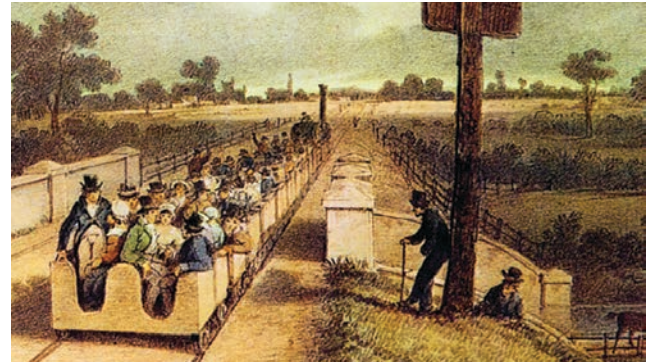
2003
Bigelow, Lepeshkin and Boyd (pictured)
Produce "Slow" and "Fast" Light



2003
First Flight of a Laser-
Powered Aircraft



The Tulip Folly by Jean-Léon Gérôme, 1882 / Wikimedia Commons



Inaugural journey of Liverpool-Manchester Railway by A.B. Clayton, 1830 / Wikimedia Commons

Tulips or railways?

The fiber optic bubble has been compared to the Dutch “tulip mania” of the 17th century—or, perhaps more productively, to the British “railway mania” of the 1840s, when similar technological ferment led to massive overinvestment.

jobs, 20 percent of its work force. In a 9 May plenary talk at CLEO 2001 in Baltimore, JDSU CEO Jozef Straus said ruefully, “I learned that the laws of gravity apply up and down.” At first the hope was that system makers had over-ordered, but installations also began to slow.

The fiber market had run full speed off a cliff—but for a while, the “laws of cartoon physics” took hold. Like the cartoon character Wile E. Coyote, the industry’s legs kept churning, and the industry hung suspended in mid-air until it looked down. The big question by mid-2001 was whether it would hit the ground with a pancake-like splat, or pop up on its feet and zoom off like Coyote’s arch-nemesis, the Roadrunner.

Stocks kept dropping through the summer, and system makers were hurting. In September 2001, Nortel stock had dropped to 7.2 percent of its value a year earlier—less than the return value of empty beer bottles in states with a deposit law. Global Crossing, which had built a massive fiber optic network, filed for Chapter 11 bankruptcy on 28 January 2002, owing huge amounts to vendors.

By the 2002 OFC in March, the fiber world had a whop-ping hangover from its drunken-sailor years. At an OSA Executive Forum before the show, John Ryan, head of market-research firm RHK, bravely said “unlike the concept of selling dog food on the internet, telecom isn’t going away.” Later, someone asked me what I thought of the market, which was looking more and more like the celebrated Dutch tulip mania of the early 17th century. When I replied “tulips,” he growled “Don’t say that!”

Attendance at the 2002 OFC slipped only 13 percent to 32,944, and 1,204 exhibitors had bought a total of 320,000 square feet of space. But a walk around the exhibit hall revealed some empty booths, and many tales of woe.

A plenary talk by internet pioneer Vint Cerf, then at MCI Worldcom, belatedly deflated the myth that internet traffic had been doubling every three months. Andrew Odlyzko, then at AT&T Labs, had busted that myth in 1998 based on AT&T data, but no one had wanted to listen. Optimists insisted that AT&T just wasn’t keeping up. By 2002, the net had some 500 million users, and traffic was growing at a consistent 80 to 100 percent a year. But, Cerf added, “it was never growing 800 percent a year.”

MCI itself became the biggest corporate collapse of the bubble on 21 July 2002, when it made what was then the largest bankruptcy filing in U.S. history. CEO Bernie Ebbers was later sentenced to 25 years in jail for an US\$11 billion accounting fraud. That added an ironic twist to the discovery that a February 1997 press release from Worldcom was the original source of the myth of traffic doubling every three months.

Surveying the wreckage

Attendance at OFC 2003 in Atlanta, Ga., was 15,023, less than half of the 2002 show. Ryan told the OSA Executive Forum he felt “a little like Napoleon’s army on the way back from Moscow.” The NASDAQ was under 1400, down from a level above 5000 only three years earlier. JDS Uniphase’s stock, which had peaked at a price of US\$1,227 per share during OFC 2000, hovered at around US\$23, a 98 percent plunge. Lucent had laid off more than 70 percent of its staff. Barely used fiber test equipment was selling for pennies on the dollar on eBay.

The internet kept growing. Odlyzko estimated U.S. backbone traffic at 27,000 to 50,000 terabytes per month in the first half of 2001, a number that sounds impressive. But spread evenly through a month, that traffic averages to just 80 to 150 gigabits per second—16 10-Gbit/s channels in a single fiber. At that rate, the average was about 600 Gbit/s in early 2003.

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The post-bubble network was vastly overbuilt and underused. In late 2002, consulting firm TeleGeography estimated only 10 percent of the long-haul fibers installed in Europe and North America carried any signals, and that only 10 percent of the wavelengths in those fibers were lit. Route maps showed that even the busiest intercity routes had only a few 10-Gbit/s channels, with many routes carrying only 2.5 Gbit/s or 622 Mbit/s. Soon, creditors were trying to unload dark-fiber networks for pennies on the dollar.

A few entrepreneurs made optical fortunes by selling out early. But paper profits at the peak of the bubble were as illusory as those from Bernard Madoff’s infamous Ponzi scheme that occurred later in the 2000s. Oldyko estimates that the collapse vaporized some US\$2 trillion of stock valuation—roughly 30 Madoffs—not counting investments in failed startups. Companies including Ciena, Corning and JDSU weathered paper losses in the billions. Lucent did not; mortally wounded, it merged with the French Alcatel in 2006. Nortel went bankrupt in January 2009 and was liquidated, with Ciena picking up some operations.

Assessing the impact

Since the bust, internet traffic has continued growing, slowly filling the network of dark fibers. The 10-Gbit/s DWDM technology that emerged during the bubble came to dominate the global fiber backbone network. Now, a new generation of coherent fiber optic systems transmitting 100 Gbit/s per wavelength is replacing them. Coherent transmission allows electronic dispersion management, overcoming earlier dispersion problems. With coherent technology, standard single-mode fibers installed during the bubble can transmit on 100 channels in the erbium amplifier band, a total capacity of 10 Tbit/s.

Enough dark fiber remains in Europe and North America to accommodate years of further growth. Next year, Microsoft and Facebook will complete a transatlantic cable with eight pairs of new large-effective-area fibers, each capable of carrying 20 Tbit/s. Space-division multiplexing, now in the laboratory, could further multiply fiber capacity.

The award of the 2009 Nobel Prize in Physics to Charles Kao recognized the tremendous importance of fiber optics as the backbone of the global telecommunications network. No other technology can match fiber capacity and cost for long-haul transmission. Without fiber, the internet would be much slower, much less capable, and much more expensive, and

features like cloud computing and video streaming would be impractical. Technologically, fiber communication has been a brilliant success.

The bubble warped the financial picture. Looking back, Oldyko compared the millennial bubble to the British railway mania of the 1840s, rather than the Dutch tulip mania of the 17th century. Railways were a revolutionary technology involving huge investments and massive construction over five years. So were personal computers, the internet, and fiber optics, which emerged almost perfectly in phase to amplify each other’s effects.

Yet technological revolutions can change the rules faster than industry and investors can keep up. Traditional telecommunications systems considered bandwidth as a scarce but essential commodity, as summed up in a bubble-era ad: “You can never have enough bandwidth.” Fiber changed the rules, because WDM could multiply bandwidth faster than demand could increase. But investors and the industry, still believing bandwidth was inherently scarce, charged off the cliff. Only well into 2001 did they realize they couldn’t make a profit selling bandwidth that fiber had made “virtually free.”

Looking back, the most important lesson from the fiber optic mania may be that the most successful technological revolutions can be the messiest. The bigger the profit potential, the more manic investors become and the less critical judgement they use. The investors who threw money at optics at the peak of the bubble probably would bankrupt us all if we ever hit a true “technological singularity.” **OPN**

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