Lasers in Science and Industry:
A report to OSTP on the contribution of lasers to American jobs and the American economy

Honoring the 50th Anniversary of the Laser
The theoretical foundation for the laser can be traced back over 100 years. Early in the 20th century modern quantum physics replaced the classical theories of light and matter. Western Europe was the epicenter of this extraordinary scientific revolution until the events surrounding World War II disrupted this remarkably productive period in physics. Many leading Western European scientists involved in quantum mechanics theory and experiment were displaced by the war, often choosing to migrate to the US to continue their research. After the war the US offered unparalleled resources supporting scientific research and innovation: intact and well-funded university, government and industry enterprises, as well as a free-market economy which rewarded entrepreneurship.

This dynamic research environment in the US created the perfect setting for the invention of the laser.
The laser has moved in fifty years from “a solution looking for a problem” to a key technology which enables major sectors of the US economy.

Laser devices are the core technology in instruments performing vital functions in many industries including transportation, healthcare, and telecom.

**Information technology:** Lasers fabricate CPUs and memory integrated circuits, manufacture LCD display screens, and encode/read information to and from optical CDROM and DVD disks.

- **Lasers enable e-commerce online transactions.** Barcodes printed on the packaging of almost every commercial product are read by laser scanners.

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<tr>
<th>Commerce:</th>
<th>Lasers cut sheet metal for cars and airplanes, cloth for clothes, scribe photovoltaic panels for solar energy, print serial and lot numbers on food and medicine packaging, shell peanuts, and sort eggs.</th>
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<td>Consumers are shifting from “Bricks and mortar” to convenient on-line shopping, saving much time and energy.</td>
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<th>Science, environment, energy, time-keeping:</th>
<th>Lasers are the invisible gears in the mechanisms of the world’s most accurate clocks. Lasers provide the fastest strobe lights for studying chemical reactions and are the sources powering research to develop inertial fusion—a limitless carbon-free source of energy.</th>
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<td>Next generation Global Positioning Satellites will use lasers to drive atomic clocks for greatly improved accuracy and reliability</td>
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<td>Lasers are used to create the hottest temperatures on earth to study laser fusion (NIF) and the coldest objects on earth to study new states of matter (BEC).</td>
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**Telecommunications and internet:** Lasers transmit virtually all the information on the internet and almost all voice communications over fiber-optic networks.

- **Lasers power the U.S. telecommunications industry, $1.1 trillion in 2008.**
- **Lasers have created a million jobs in the telecommunications industry in America.**

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<th>Medicine:</th>
<th>Lasers help prevent blindness and improve vision, provide personalized medicine by decoding a patient’s genome, and diagnose cancer and AIDS.</th>
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- **Laser based gene sequencers are millions of times faster than older methods.**
- **Lasers save many lives each year and help reduce the cost of medical care.**

Fred Schlachter and Thomas Baer
Lasers in Manufacturing: Lasers make light work in heavy industry

Automobile doors: Lasers weld where classic arc welding does not work.
- Lasers easily weld materials of different thickness: car doors are made lighter in weight and stronger, improving fuel economy.
- Traditional arc welding warps sheet metal when attaching hinges to door frames.
- Lasers make cars stronger, safer, lighter and cheaper.
- Lasers make hundreds of parts for a modern car.
  - weld seat frames
  - harden torsion springs
  - mark parts
  - cut and weld airbags
  - weld antilock brakes
  - cut body parts
  - drill holes in fuel injectors
- Lasers precisely machine borders on thin-film solar cells and provide accurate dopant profiles to increase solar cell efficiencies.
- Solar panels: Lasers improve fabrication and efficiencies of thin-film solar cells.
- Jet engines and gas turbines for generation of electricity are more efficient because laser-drilled holes improve cooling.
- Powerful lasers can be used to drill millions of precisely shaped and accurately located holes in difficult materials.

Turbine engines: Improving efficiency requires advances in cooling. Lasers quickly drill millions of small holes.
- Pre-laser era.
  - Holes drilled by mechanical means*
  - Engine components require hardened steel and ceramic materials which dull drill bits and blunt saw blades.
  - A laser beam never dulls, and is ideal for precision drilling and cutting.
- Lasers drill millions of precision holes.
- Jet engines and gas turbines benefit from laser-drilled holes.
- Jet engines and gas turbines for generation of electricity are more efficient because laser-drilled holes improve cooling.
- Powerful lasers can be used to drill millions of precisely shaped and accurately located holes in difficult materials.
- Lasers are a tool which never gets dull. Their use produces better products and reduces heavy-metal contamination of the ecosystem.
- Engine components require hardened steel and ceramic materials which dull drill bits and blunt saw blades.
- A laser beam never dulls, and is ideal for precision drilling and cutting.
Lasers in Medicine and Biotechnology: Saving Lives Improving Health Reducing Cost

Eye surgery: Lasers improve health and well-being of patients.

Lasers allow ophthalmologists to correct many problems in different locations in the eye, fixing retinas, reshaping corneas, and helping forestall blindness in diabetic patients.

Cornea LASIK
Cataract Surgery
Retina Reattach

Ultraviolet Laser
Pulsed Infrared Laser
Green Laser

Detached retina repaired with laser: Gold-medal Chinese diver Gu Jingjing (courtesy tksteven)

Medical devices: Lasers save lives.

Lasers produce “impossible” micromachined components

Precise sterile machining of hard materials

Stents

Gene sequencing: Lasers power the latest medical diagnostic instruments.

1975: 2000 base pairs/day
1990’s: 100,000 base pairs/day
Today: two billion base pairs/day

One day’s data would fill one half page in a book.
One day’s data would fill a chapter in a book.
One day’s data would fill ten encyclopedias.

Pre-laser DNA sequencers (1970’s) could sequence 2000 base pairs per day.
1990’s laser-based DNA sequencers could sequence 100,000 base pairs per day.
Today’s laser-based DNA sequencers can sequence two billion base pairs per day.

Time to sequence a single human genome: 4000 years.
Time to sequence a single human genome: 80 years.
Time to sequence a single human genome: 1 day.

A million-fold improvement in speed since 1975!


Rapid laser-based sequencing of human genomes opens the door to personalized medicine and individualized therapies.

Fred Schlachter and Thomas Baer
Lasers in Telecom and Information Technology: Internet  E-commerce  Personal Computers

Real-time two-way communication: Lasers and fiber optics have greatly increased the speed of real-time communication.

Ancient times through 19th century
Information transmitted by smoke and fire

Visual information carried over 100 km distance with very low bandwidth.
RATE ~ 1 character/10 sec
Time to transmit the Gettysburg Address: hours

20th century
Electrons through copper wires

Electrons carry information through copper wire over 1000s km with moderate bandwidth.
RATE ~ 100 characters/sec (1970's), ~100,000 characters per second (1990's)
Time to transmit the Gettysburg Address: seconds

21st century
Laser light through fiber optics

High-bandwidth communication using infrared lasers and fiber optics to guide the light.
RATE ~ 100 billion characters/sec ~ a million times faster than copper wire
Time to transmit the Gettysburg Address: 10's of nanoseconds

Lasers in information storage: CDs and DVDs
A case study in enabling technology:
The invention of the laser spurred development of many applications. Diode lasers have an annual impact on the U.S. market of more than $200 billion.

Microelectronics: Lasers produce almost all microprocessors and memory chips in personal computers.

UV Lasers in Photolithography
10 Billion CPUs Produced in 2008

Pulsed lasers in redundant memory repair
Memory Chip $20 Billion in 2009
Lasers print the vast majority of IC circuits in the $260 Billion microelectronics industry

Basic research:
Laser invented in 1960

The laser in 1960 was deemed: "A solution looking for a problem"

In 2010, 500 million infrared diode lasers will be produced

These lasers power many different instruments.
For example:
CD-ROM/DVD
Optical disk drives $3 billion

Laser instruments are built into larger systems
Optical drives incorporated into personal computers $60 billion

Fred Schlachter and Thomas Baer
New breakthroughs build upon the unique properties of the laser

**High frequency:** encodes enormous amounts of information
Application: supercomputing, telecommunication

**Focusability:** focuses to small spots (less than 1/100 of width of hair)
Application: optical data storage

**Power:** precisely delivers high intensities to small areas
Application: manufacturing, cutting and welding, surgery

**Short pulses:** generates pulses shorter than 1 femtosecond (a million billionth of a second)
Application: advancing our understanding of biology, physics, and chemistry, stroboscopic pictures of atoms and molecules in action

**High fields:** produces ultra-strong electric fields
Application: compact particle accelerators

**Large pulse energies:** creates pulses shorter than 10 billionths of a second with energies greater than a stick of dynamite
Application: drilling, laser fusion

**Monochromaticity:** emits ultra-pure colors
Application: atomic clocks, astronomy, metrology

**Coherence:** forms highly order light waves
Application: holography, astrophysics

Going where no laser has gone before!
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