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NATIONAL ACADEMY OF SCIENCES
NATIONAL RESEARCH COUNCIL

DIVISION ON ENGINEERING AND PHYSICAL SCIENCES
NATIONAL MATERIALS ADVISORY BOARD

WHITE PAPER FOR A PROPOSAL

HARNESSING LIGHT II – PHOTONICS FOR 21ST CENTURY COMPETITIVNESS

BACKGROUND

Optical science and engineering (OSE) has been foundational for many of the scientific and technical advances of the past 100 years and is one of the key transformative disciplines driving innovation in the 21st century economy. In 1998, the National Research Council through the Board on Physics and Astronomy and the National Materials Advisory Board issued a landmark report, *Harnessing Light, Optical Science and Engineering for the 21st Century*,[1] that not only captured the importance of optics and photonics but also described the major challenges facing the field. As the first comprehensive report in the field of optics, *Harnessing Light* clearly demonstrated that optics is an enabling technology to many industrial, governmental, military, and healthcare organizations and a cornerstone of future innovation.

In the past ten years, enormous progress has been made in the development of photonics technologies. OSE is headed toward another strong growth period, driven by developments in solid state lighting, solar technologies, sensors, lasers, imaging, fiber-optic communications, digital photography, diagnostic medicine, computing/processing, and consumer displays/TVs with markets ranging from energy and healthcare to communications and security.

While the Harnessing Light report has been extremely useful to both U.S. and foreign,[2] academic, industrial, and governmental organizations, OSE has advanced over the past decade to a point where a revisiting of the scientific and policy issues would be timely. A new report would address the role photonics plays in national competitiveness and innovation —in particular, the infusion of photonics-related technologies into mass market applications that depend heavily on manufacturing costs. More economical, multifunctional manufacturing capabilities are needed to keep the U.S. competitive. The new study could identify national strengths and weaknesses in relation to current and future needs including economic impact, workforce needs, and future research directions. Since the 2007 NRC report *Controlling the Quantum World: Atomic, The Science of Atoms, Molecules, and Photons*[3] covers much of the area of basic optical science, among other areas, this proposed study would consider the technology areas where optics is an enabler that can really impact the economy of the country.

What Has Changed?

[1]National Research Council, *Harnessing Light: Optical Science and Engineering for the 21st Century,* National Academy Press, Washington, D.C., 1998.
[2]Photonics 21, Toward a Bright Future for Europe, European Technology Platform Photonics 21, Dusseldorf, Germany, 2006.
[3]Controlling the Quantum World is available at http://www.nap.edu/catalog.php?record_id=11705

Since *Harnessing Light* was issued in 1998 major developments have occurred in the field. A few examples of these are:

- Fiber optic telecommunications: optical technology has enabled high bandwidth communications.
- Quantum communications: laboratory demonstrations have showed that long-distance, low-error-rate communications using pico-watts of power are possible.
- Solar energy and other energy efficient devices: the development of devices for the efficient and economic conversion of sunlight to other energy forms and the development of light emitting diodes (LEDs) that operate efficiently and at various wavelengths of use as well as other types of semiconductor-based lighting are contributing to future energy independence.
- Optics for environmental sensing: optics is playing an expanded role in sensing, measuring, and monitoring the changing environment.
- Nanophotonics quantum optics, and quantum information processing and quantum cryptography: these will revolutionize computing and communications and offer new techniques to overcome the fundamental physical limitations of Moore's Law in traditional CMOS electronic circuits.
- Biophotonics: the interaction of light with tissue provides valuable techniques for medical diagnosis, such as new imaging modalities, and in the treatment of various illnesses and in molecular sequencing and genomics.
- Ultrahigh resolution microscopy: Single photon emission is being exploited to conduct high resolution studies of biological systems and other systems.
- Ultrafast lasers and detectors: allow the study of physical processes on very short timescales leading to new insights in basic research in physics, chemistry and biology which would have applications in chemical sensing and pharmaceutical design. Pushing light to extremes generates enormous electric fields used to produce exotic states of matter and produce powerful x-ray lasers to irradiate complex biological systems to learn more about the processes of life.
- National security: advances in multi-wavelength and hyperspectral imaging will improve sensitive night-vision systems, laser-guided munitions, and optical sensing of chemical and biological agents.

What is the international situation?

Harnessing Light has had major international implications in optics and photonics. The comprehensive “Deutsche Agenda Optische Technologein für das 21. Jahrhundert” specifically acknowledged the *Harnessing Light* report as its stimulus.

In 2004, the European Commission encouraged the development of an industry-led initiative which resulted in their 2006 report, *Photonics21, Towards a Bright Future for Europe,* focusing on issues raised in the U.S. report. Photonics21 now comprises more than 900 stakeholders from 32 countries with almost 50 percent of the members coming from industry.

In 2006, the UK Department of Trade and Industry worked with the research community to produce its own report “Photonics: A UK Strategy for Success. Painting a Bright Future.” Korea has a similar report, Photonics 2010, highlighting the importance of optics and *Photonics in Europe: Economic Impact* was released be Photonics21in December 2007. According to the European Economic Impact Report, only 15% of photonics production occurs in North America.

Many countries have recognized the importance of optics and photonics and are moving forward. The United States cannot afford to fall behind.

What is the situation in the United States?

Since 1998, industrial research labs such as Bell Labs, Kodak, IBM, Hughes Research Lab, and Rockwell have all but disappeared and many optics-related manufacturing and development industries, like the U.S. display business, have moved overseas. U.S. companies no longer have significant market share in one of the most sophisticated optical technologies, and one with huge economic leverage: microlithography.

The United States has seen the establishment of new optics programs in U.S. universities and the emergence of the first colleges of optics and photonics. These recognized centers of excellence are making valuable contributions to the field and are training the next generation of experts and workforce for industry.

Statement of Task

A committee of the National Academies will be convened to:

1. Review and comment on the findings and recommendations of the NRC *Harnessing Light* report;
2. Identify the technological opportunities that have arisen from recent advances and accomplishments in optical science and engineering;
3. Assess the current state of optical science and engineering in the United States and abroad, including trends in private and public research, market needs, examples of translating progress in photonics innovation into competitiveness advantage (including activities by small businesses), workforce needs, manufacturing infrastructure, and the impact of photonics on the national economy;
4. Prioritize a set of research grand-challenge questions to fill identified technological gaps in pursuit of national needs and national competitiveness;
5. Recommend actions for the development and maintenance of global leadership in the photonics driven industry—including both near-term and long-range goals, likely participants, and responsible agents of change;

Approach to the Study
In carrying out this charge the committee will consider issues such as

- The current research portfolios both nationally and internationally in optical science and technology;
- Considering U.S. industrial capabilities and needs in photonics research;
- The current role of small businesses in generating and exploiting photonics technologies.
- The role of university-industry relations in OSE.
- Assessing obstacles to technological development of photonics technologies.
- Identify research and educational imperatives that are necessary to improve our economic and scientific competitiveness in photonics science and technology?

Many of the fundamental science issues have been considered in recent NRC reports and it is proposed that the focus of this study should be on identifying the engineering and manufacturing technology challenges that need to be addressed to translate the compelling progress in

fundamental science into a competitive manufacturing advantage for the United States. In this regard the committee shall also consider previous work on this issue including NRC reports such as *Nanophotonics: Accessibility and Applicability (2008); Innovation in Global Industries: U.S. Firms Competing in a New World (Collected Studies)(2008); Controlling the Quantum World: The Science of Atoms, Molecules, and Photons (2007); Innovation Policies for the 21st Century: Report of a Symposium (2007) Government-Industry Partnerships for the Development of New Technologies (2002)*.[4]

[4] Nanophotonics: Accessibility and Applicability is available at http://www.nap.edu/catalog.php?record_id=11907; Innovation in Global Industries: U.S. Firms Competing in a New World (Collected Studies)is available at http://www.nap.edu/catalog.php?record_id=12112; Controlling the Quantum World is available at http://www.nap.edu/catalog.php?record_id=11705; Innovation Policies for the 21st Century: Report of a Symposium (2007) is available at http://www.nap.edu/catalog.php?record_id=11852; Government-Industry Partnerships for the Development of New Technologies (2002) is available at http://www.nap.edu/openbook.php?record_id=10584&page=2.