Photonic Technologies in the 21st Century : Creation of New Industries *

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ABSTRACT

As we approach the new millennium, the ongoing aim of human society is not only for promoting scientific technology but also creating new industries. To achieve this goal, each person in industry must recognize anew that the real meaning of science is to explore the absolute truth. It is also important that people recognize that there are unlimited matters which we humans do now yet know.

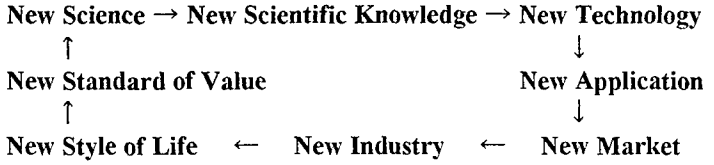
1. INTRODUCTION

The 20th century was one that witnessed many great discoveries and our knowledge increased many times during the last one hundred years. Yet even with such an explosion of knowledge and information there is much more that we do not yet understand. Our present knowledge represents only a fraction of what there is to know. For example, there have been major breakthroughs in understanding cell structure by studying individual components or systems such as the role of calcium ions in signal transduction. However very little is known about how all of these components work in concert. It is very much like trying to understand an orchestra by studying the individual instruments. In the future we will develop methods to study the function of the entire cell not just individual systems. On the molecular level we are just beginning to study the details of molecular dynamics during a chemical reaction. The work of this year's Nobel Prize winner in chemistry, Dr Zewail shows how it is possible to use photonics to study the intimate detail of a chemical reaction. Once we gain such detailed information about more complex systems it will be possible to more efficiently produce the chemicals we need and to destroy those that we no longer require.

At Hamamatsu Photonics it is our corporate mission to provide photonics technology that will help us to gain new knowledge of the world we live in. Photonic technologies are very unique in that they let us observe the parts of the world that are very far away (thousands of light years), very small (nanometers) or happen very quickly (in femtoseconds). The roots of our company can be found in the pioneering spirit of Professor Kenjiro Takayanagi who independently developed the technology of television despite the fact those around believed it could not be done because it had never been done. Professor Takayanagi hoped to develop a new way for people to experience the world. We inherited his spirit and continue this idea by using photonics to gain knowledge as well as improve the quality of life for all people.

In the twenty first century it will be possible that we could make all of mankind healthy. Not just in a physical sense but in the definition of the World Health Organization where "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." Photonics has the potential for creating the knowledge and industry that could make this possible. It is our hope that this new century sees the beginning of a new economic cycle shown in Figure 1. While industry is designed to generate profit, the purpose of industrialization is for all of mankind to share a common understanding of the New Life Style and to benefit from the New Standard of value, namely Health as defined above.

Figure 1:



*Also published in Proceedings of SPIE Volumes 4078, 4079, 4081, and 4082

In *Input/Output and Imaging Technologies II*, Yung-Sheng Liu, Thomas S. Huang, Editors, Proceedings of SPIE Vol. 4080 (2000) • 0277-786X/00/$15.00

Through the application of photonics we are now beginning to develop the New Science that will lead to the cycle illustrated in Figure 1. In this cycle, mankind is constantly improving its status by using new technologies to discover new knowledge. The application of this new knowledge leads first to new industries and then to a change in the social fabric of society. We understand that this is a very long-term goal. But mankind needs to dream in order to progress. Only by trying to see over the horizon can we discover something that will radically improve all of our lives. Thus while Hamamatsu Photonics' short-term goal is to generate profits, these profits are to be used in the quest for new knowledge which is our long-term target.

2. TECHNOLOGIES

This paper will discuss several technologies that are key to the development of new knowledge which will eventually produce new industries. Application of these technologies will be also discussed.

A. The Ultimate Laser Photon (Photon Factory)

The light emitted by a laser is unique in that it is monochromatic, coherent and directional. These properties have made laser-generated photons vital to all types of research ranging from biology to high-energy physics. We need to obtain a better understanding of exactly what is a photon and how it interacts with the world. By better understanding the photon on a fundamental level we will be able to use it more effectively. Phenomena such as the particle wave duality and teleportation must be better understood through a study of the photon.

The development of very small terawatt and pedawatt laser systems give many researchers access to inexpensive ultra high power. New physical phenomena are being discovered when such intense laser beams interact with matter because these lasers create electric fields much greater than those seen in any other experiment do.

B. Ultra Fast Measurement Technology

By continuing to push the speed at which we make measurements we will discover greater detail of how our world operates. We now have lasers that are capable of measuring the individual motion of atoms in molecules. Newer and faster methods will help get even greater detail of how molecules react. Even faster methods will allow us to follow the motion of electrons during important chemical reactions such as photosynthesis or vision.

C. Optical Correlation Technology

Even though we have discovered only a small fraction of our knowledge, we are severely limited in using it because even this limited amount of knowledge is to great to process with conventional computer systems. We must learn how to process information in parallel with optical processors such as spatial light modulators. Ultimately our goal is to process information in 3 or more dimensions using technology that must still be invented.

D. Forecast Simulators

With time not only has our information become too complex, but also the questions we need to answer become more difficult. As our planet's population increases and our technology becomes more complex, the risk of answering a question incorrectly grows exponentially. For example, the consequences of incorrectly predicting the outcome of global warming will be severe if we either under estimate or over estimate the significance of burning fossil fuels. Premature curtailing of fossil fuels will severely curtail the growth of developing countries leading to unnecessary pain and suffering. Failure to prevent global

warming will have even worse consequences. We need better methods to simulate events or conditions so we can better guide environmental, economic, technical, political, and military decisions.

Ultimately nations will never again fight a war on the battlefield but instead will use simulations to replace them. The simulations will simultaneously decide the output as well as convince the parties that physical conflict is too costly.

E. High Power Lasers

Photons are capable of doing many important things such as curing cancer, printing this manuscript or repairing an integrated circuit. At very high photon densities there are many new things that photons can do. At present, it is expensive to generate a lot of photons because the photon sources are expensive. Semiconductor laser diodes hold the promise of being able to reliably and inexpensively generate photons for many new and exciting applications. Just like the replacement of the vacuum tube with the transistor and then to the integrated circuit, so too will the semiconductor laser evolve and result in important technologies and new industries that we cannot even imagine today.

F. New Photochemistry

Much of our planet's energy is wasted in creating chemicals that we need to live or to improve our lives. Lasers are capable of creating specific excited states. Finding ways to selectively excite molecules so that they can be moved along specific reaction pathways will lead to huge savings in cost, energy and pollution. New knowledge on how to perform pathway specific photochemistry is vital to the goal of making everyone healthy according to the World Health Organization's definition of health.

3. APPLICATIONS

We can only speculate on what the full effect of such new photonic technologies will have in the long term. However over a short period of time we can easily imagine some of the benefits we might enjoy from these as well as other photonic technologies. Some of these benefits are discussed below.

A. Measurement of Physiological Functions

The pulse oximeter has already found an important role in guaranteeing that the oxygen concentration of the blood is maintained at as close to optimum as possible. Countless lives have been saved and others have had severe injury prevented by this simple optical device. Not very far away are devices that will permit rapid and painless screening for diabetes. Noninvasive cancer diagnosis is already being tested in clinical trials.

Ultimately a device will be available that checks your body's functions on a daily basis. It screens for potential problems before they cause disease. Adjustments to exercise, diet or even administration of drugs can be performed before the individual is aware of a problem. Such an advanced detection system would save costs, pain and anxiety. It would go as long way to attaining the goal of making people truly healthy.

B. Optical Medicine

In the past few years, photodynamic therapy has been shown to be a valuable treatment for some forms of cancer. In some cases it is far more useful than other techniques such as surgery because it leaves the effected organ in tact. Therefore for young women, cancer of the cervix no longer means that it is the end of their dream to have a family. For older people suffering from the wet form of macula degeneration, photodynamic therapy will soon be used to prevent the blindness caused by this disease.

New chemicals are being developed that are absorbed faster by the cancer cells and discharged more rapidly by the body. This will make treatment simpler and more effective. Patients may not even need to stay overnight in a hospital. Presently PDT can only be used on cancers that are found on a surface. Techniques are being developed that will be used in the treatment of cancers that are deep inside an organ.

Cosmetic uses of photons for hair removal, port wine stain removal or tattoo removal make it easier for a person to be accepted by society. These applications are far from superficial since they greatly improve the quality of life for those that need them.

Other applications of photonics to medical practice will certainly emerge in the near future for things such as the treatment of stroke, heart disease, healing of wounds and reducing or relieving pain.

C. Early Detection of Disease

Cancer screening using Positron Emission Tomography (PET) holds the promise of early detection and cure of this terrible affliction. Injection of fluorodeoxyglucose into the blood stream is current used to uncover cells that are metabolizing at rates faster than those of their neighbors. These cells are then analyzed to determine if they are malignant. Such a screening method could in the near future make an entire city cancer death free.

Light CT uses nonionizing infrared photons to take a three dimensional image of the body. Work is under way in many places around the world to use light CT as a method for detecting breast cancer. This technique could be less expensive than x-ray methods and used safely on all individuals including pregnant women. Other uses of the light CT would be to quickly determine if a stroke is caused by ischemia or a hematoma. Such information is vital in determining the correct treatment. Rapid treatment of stroke can greatly reduce the damage to the brain resulting in a patient that can lead a normal life even after such a severe trauma.

In the future we hope to quantify the health of a person, not just the presence of disease.

D. Fiberless Optical Communication

Information is the most important commodity in our society. We are constructing very large and expensive infrastructures to move information from one location to the other. Fiber optics is one of the key technologies for information transport because of the very high capacity available due to wavelength division multiplexing. This technique suffers from the fact that fibers must be placed between locations. At Hamamatsu Photonics we have developed a series of fiberless optical communications systems. These operate by transmitting the optical signals through air. They have the capability to send data, or video without the need for government licenses or owning a right of way. One such a fiberless system is used at sporting events such as golf tournaments to transmit the video camera output to the broadcaster's trailer or even back to a studio. Such a system was used at the Atlanta Olympics and is now being tested in Hamamatsu City. In our hometown it is being used to connect elementary schools with the city hall. It could also be used to connect remote clinics with the medical school for telemedicine.

E. Health Industry for Successful Aging

Many countries will soon suffer from an increase in their average age. In the past such an increase in age would greatly burden society in terms of medical expenses and the cost of financially supporting an aging population. We believe that it is possible to completely eliminate the impact of a graying population by finding ways to reduce the pace and effect of the aging process. At Hamamatsu Photonics we are using photonic technology to understand how locomotion is effected as a person ages. We hope to develop exercises that will prevent the loss of mobility and greatly reduce the probability of an older person falling. While just a small step, it will have a big impact on the quality of life of our seniors.

F. Disposal of Industrial Waste

High power lasers and controlled photochemistry hold the promise of being able to safely dispose of dangerous waste products. It will do this by selective destruction of the dangerous ingredients into less danger or even harmless smaller molecules. These smaller molecules can then be recycled into new products.

G. Search for New Energy Sources

Perhaps the biggest impact that photonics can have on mankind is the development of clean and inexpensive energy. For once this is available; the quality of life of the entire world can be improved without damaging the plant. We must continue our search for a way to harness laser fusion and solar energy for they are needed to make the world a better place to live for all of us.

Photonics holds the promise of creating New Science and New Technology which will lead to New Industrial and of course to a world population that is truly healthy.