UNIVERSITY OF NAIROBI

LASERS: THE SPLENDOUR OF LIGHT

INAUGURAL LECTURE

BY

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Professor Otieno was born in Bondeni, Nakuru, at the height of the Second World War on 20th April, 1942, being the second of two sons of a Postal Clerk, the late Mzee Asa Osanya.

His primary education took him through Hawinga, Unyolo and Hono Primary Schools in Alego Location of what is now Siaya District before he joined the Alliance High School in 1957. In 1963, after his Cambridge Higher School Certificate examination, he won a scholarship, which was open to the whole Commonwealth, to go to Worcester College Oxford where he studied Engineering Science. Upon completion of his studies at Oxford he returned to Kenya holding both a Bachelor of Arts in Engineering and A Bachelor of Science in Electrical Engineering to embark on his academic career when he was appointed assistant lecturer in the Department of Electrical Engineering in 1968, in the then Nairobi University College which was a constituent of the University of East Africa.

In 1969 he was awarded a Unesco Fellowship to study for a Ph.D. degree at the University of California Berkeley. He returned from study leave in 1973 having earned both a Masters and a Doctorate at Berkeley to join the University of Nairobi as a Lecturer in electromagnetic fields, microwave engineering and telecommunications.

In 1975, he was promoted to Senior Lecturer and 1976 made the Chairman of the Department of Electrical Engineering. In 1979 he was elected Dean of the Faculty of Engineering and a year later promoted to the Post of Associate Professor. For reasons beyond his control in 1982 Professor Otieno had to interrupt his academic career until 1987 when he rejoined the University of Nairobi at the same level of Associate Professor. In 1988 he was again appointed Chairman of the Department of Electrical Engineering. The following year he was promoted to Full Professor. A year later he was elected again as the Dean of the Faulty of Engineering which he still currently is.

Professor Otieno did much of his early research in Quantum electronics which deals mainly with lasers. One of his contributions in this field was the invention of the Helium-Neon waveguide laser which he did together with Dr. P. W. Smith of the Bell Telephone Laboratories in New Jersey, U.S.A. He also researched into the effects of collisions in atomic gas lasers and has published outstanding papers in that field. Later on his research changed to the area of Microwaves and Telecommunications. With his graduate students he has contributed significantly in this area as evidenced by his publications, especially in telecommunications systems in East Africa.

On the professional side, he is a Registered Engineer (Kenya) and a Partner in Westconsult, a leading Engineering Consultancy firm. He is the current Secretary of the Institution of Engineers of Kenya, a Member of the Institute of Electrical and Electronic Engineers and a Fellow of the Kenya National Academy of Sciences and its Chairman of the Physical Sciences Specialist Committee. He is the Chairman of the Committee for Engineering Education of the Inter-University Council of East Africa. He has served as External Examiner in Electrical Engineering in several Universities including Makerere, Zambia, Dar-es-Salaam, Moi and Jomo Kenyatta University College of Agriculture and Technology.

On national development, he served as a member of the Board of Directors of the defunct Kenya External Telecommunications Company, KENEXTEL, and as a member of the former East African Examination Council. He has also participated in the drafting of several important standards for the Kenya Bureau of Standards.

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LASERS: THE SPLENDOUR OF LIGHT

1. INTRODUCTION

When lasers were discovered, the general expectation was that they would revolutionize civilization. In the first ten years this expectation was slow to materialise; in fact the laser was then regarded as "a solution in search a problem". It was also generally agreed then that a research student with no subject to work on automatically resorted to laser work and this is exactly what happened to me. When I had run out of ideas about a topic for my Master's research I decided to try my luck in laser work. That was in 1966, over a quarter of a century ago.

It is now over thirty years since Theodore Maiman experimentally operated the first laser, whose medium was a pink ruby crystal, in 1960. Since then, not only has the term laser been adopted into our everyday vocabulary, but the laser has grown from the status of a scientific curiosity in the laboratory with a few potential applications to that of being one of the most important inventions of our time. Far from being "a solution in search of a problem" the laser today can truly be described as a solution to a vast number of problems. It is now a vital tool in areas as diverse as manufacturing industries and medicine, an essential component of communication and holographic systems and the basis of many scientific measurements and research activities.

There are many types of lasers with quite different characteristics, but they all emit radiation with special properties which make possible their use in a much wider range of applications than conventional light sources.

2. LASER ACTION

The word LASER is an acronym for the phrase "Light Amplification by Stimulated Emission of Radiation" so that by definition, it is a device which amplifies light by means of stimulated emission of radiation. In practice a laser is generally used as a source or generator of radiation with wavelengths ranging from the far infra-red to X-rays. Laser outputs can either be light pulses or continuous light.

Although (or perhaps because) laser action is essentially a quantum process, it is very simple to understand qualitatively. It is based on two fundamental laws of nature. The first law stipulates that a system of particles are in a stable equilibrium if their total energy is a minimum in that state. As far as the electronic energies of (say) electrons in a crystal lattice at a given temperature are concerned, this means that they will try to be in their lowest energy level. This fact, taken together with the Pauli exclusion principle which states that only two electrons can be in each energy level, and on the basis of energy being quantised leads to the so called Fermi-Dirac statistics which predicts that for a collection of atoms under normal conditions (i.e. in thermal equilibrium), there are always more atoms which have electrons in the lower energy level than those with electrons in the higher energy level at high energies.

The second principle of laser action is simply that what goes up must come down. Or, if a system contains electrons in two energy levels, then an incident photon of energy corresponding to the difference of the levels is as likely to cause any single electron in the lower energy level to jump to the higher level as it is to cause a single electron in the upper level to jump to the lower level. A down transition corresponds to a photon being radiated and an up transition to a photon being absorbed so that energy is conserved.

In an excited atom, one of the electrons is raised to a higher energy state from the one it would normally occupy. Such excited atoms can be created, for example, by heating the material as in an incandescent bulb, or by bombardment with electrons as in a discharge lamp.

After a short time, called the life-time of the level, the excited atom de-excites. In a typical gas discharge, the life-time can be of the order of 10 nanoseconds. There are as many nanoseconds in one second as there are seconds in 32 years. The electron makes a transition to a lower energy state, the energy difference being emitted as a photon or quantum of light. This phenomenon is known as spontaneous emission in which the atoms emit in an entirely random manner such that there is no phase relationship between the associated waves. It is the main process of light emission from conventional sources.

A laser on the other hand exploits another mechanism for the generation of photons called stimulated emission which was discovered by Einstein in 1917. Einstein showed that if a photon of energy equal to the energy difference associated with the transition involved is incident on the excited atom, it can induce or stimulate that atom to make a down transition thereby emitting a second photon. Ironically, Einstein rejected the quantum theory because he refused to come to terms with the uncertainty principle. "God" he quipped, "cannot play dice with the universe". There are two very important points concerning stimulated emission upon which the properties of laser light depend.

Firstly, the photon produced by the stimulated emission has the same energy as the stimulating photon and hence the associated light waves must have the same frequency. Secondly, the light waves associated with the two photons are in phase and have the same state of polarisation. This means that if an atom is stimulated to emit light energy, the wave representing the stimulated photon adds to the incident wave on a constructive basis thereby increasing its amplitude. We then have the possibility of light amplification by stimulated emission of radiation.

Stimulated radiation is coherent, that is, all the waves making up a beam of such radiation are in phase. This situation might be compared to a long column of National Youth Servicemen at Gilgil all of whom are marching in step. This is in contrast to spontaneous emission in which the atoms emit entirely randomly and there is no

phase relationship between the associated waves. Such radiation is said to be incoherent and might be compared to the (apparently) random movements of people on Kenyatta Avenue during rush hour each one walking at his pace and in his own direction. Under normal conditions of thermal equilibrium, spontaneous emission in the visible part of the spectrum from an assembly of atoms is much more probable than stimulated emission (by a factor of approximately 10^{13}) and therefore the radiation from most optical sources is incoherent.

Stimulated emission is exactly opposite to the more common process of absorption in which the incident photon is absorbed by an atom with the electron jumping from the lower energy state to a higher energy state. Thus in thermal equilibrium, since in a collection of atoms more atoms will have their electrons in the lower energy state than those with their electrons in the higher energy state, the rate of absorption of any incident photons will be higher than the rate of stimulated emission for the two given energy levels. This results in attenuation rather than amplification of any incident resonant beam.

Laser action is only possible when the atomic system departs from thermal equilibrium. A condition of thermal non-equilibrium must be created in which more atoms have electrons in the higher energy level than those with electrons in the lower energy level. This condition, called population inversion (or negative temperature), is necessary for stimulated amplification to occur.

It took many years for scientists to device practical means of creating population inversion in order to achieve coherent amplification. The first device based on this principle was operated in 1954 by Townes, Basov and Prokhorov in the microwave range. This was the ammonia maser (microwave amplification by stimulated emission of radiation) for which they won the Nobel Prize for Physics. Efforts to achieve population inversion in shorter wavelengths reached a climax in mid 1960 when Maiman demonstrated stimulated emission in a ruby crystal in the visible region corresponding to a wavelength of 6943 Angstrom. There are ten thousand million Angstrom units in one metre. Maiman achieved population inversion by exiting the crystals with a powerful flash lamp.

This method of achieving population inversion or "pumping" was quickly extended to other solid state lasers. For gas lasers on the other hand, an electrical discharge is often used to create population inversion. Other methods of pumping include passage of hot gas through nozzles, using another laser to respectively excite a particular transition, use of chemical reaction to create excited species, electron bombardment of atoms or molecules or even employing products from nuclear reaction. With all these available techniques, obtaining population inversion has become a relatively simple task and as a result, stimulated emission has been observed on a large number of transitions in various atoms, molecules, ions and solids. Indeed it is now known that population inversion actually exists naturally in the atmosphere of Mars approximately 75 km from its surface where carbon dioxide exists in an inverted state resulting in intense emission at a wavelength of 10.33 microns. There are a million microns in one metre.

In a two energy level system the probability of absorption of an incident photon resulting in an electron moving from the lower to the higher levels is equal to the probability of a stimulated emission of another photon when an electron jumps from the higher to the lower levels. Because of this, it is evident that population inversion cannot be achieved by optical pumping of a simple two level system. At best, even with very intense irradiation, the population of the upper and lower levels can only be made equal. Optical pumping, and indeed other pumping methods, requires either a three- or a four-energy level system.

In a three level system a third energy level, higher than both the transition levels (one of which is usually the ground level) is employed for the pumping. For efficient pumping, this third energy level should have a short lifetime so that it offloads its electrons to the upper transition level rapidly. The upper transition level should in turn be metastable, that is, it should have a long lifetime.

In a four level energy system, the transition levels are between a higher energy level and the ground level. In this case, the decay to the upper transition level should be rapid just as the decay from the lower transition level to the ground level. Again, if the upper transition level has a long lifetime, the pumping becomes efficient.

In a majority of cases, the gain of pumped or excited medium (a medium with population inversion) is quite small, being in the region of 10 per cent per metre or less. The amplification of an optical beam passing once through the medium is therefore minimal. In most practical systems the overall amplification is increased by placing two reflecting mirrors, one fully reflecting while the other partially transmitting, at each end of the medium. The optical beam then bounces to and from through the medium, perhaps as many as one hundred times, thereby increasing the effective length of the medium and the amplification of the beam accordingly.

The mirrors form an optical cavity or resonator called <u>Fabry-Perot resonator</u> which together with the active medium constitutes an optical <u>oscillator</u> rather than an amplifier. The mirrors introduce positive feedback to the amplifying medium in a way analogous to positive feedback in an electronic oscillator.

The Fabry-Perot resonator has several interesting characteristics. Firstly, its geometry favours photons travelling perpendicular to the mirrors which get trapped inside the cavity to undergo reflections back and forth. Rays travelling at an angle to the resonator axis escape from the cavity after only a few reflections. With the amplifying medium in the cavity a weak beam, initiated by spontaneous emission, builds up in intensity and an intense coherent beam emerges from the partially transmitting mirror. The beam is highly <u>directional</u> since significant amplification occurs only for photons moving along the resonator axis.

To ensure laser oscillation in an inverted medium, the population inversion and hence the gain within the medium must be large enough to overcome various losses, including the laser output itself, which may exist in the system. There is therefore a minimum or <u>threshold</u>

gain coefficient which is required to initiate and sustain laser oscillations.

A second property of the Fabry-Perot resonator arises from the wave-nature of light and ensures that only light at certain well-defined frequencies can grow. The presence of waves with the same frequency travelling in opposite directions within the cavity results in standing waves within the cavity whose length must equal an integral number of half-wavelengths. As a result laser emission can be very pure with frequency width considerably narrower than the linewidth associated with spontaneous emission.

In brief then, laser sources differ from conventional optical sources in that the phenomenon of stimulated emission and the characteristics of the laser resonator together provide great control on the properties of light emitted.

These properties include a high degree of collimation or directionality, monochromaticity, brightness and spatial and temporal coherence. In these characteristics lie the secret of the many great applications of lasers. These properties are supplemented by the ability to use well developed techniques such as Q-switching and mode-locking to produce precisely controlled high energy laser pulses which have opened up a wide range of applications of lasers. It is noteworthy that the advances in laser technology are closely related to those in other branches of modern technology, called hi-tec, such as modern materials, precision engineering, microelectronics, communications and computers. This relation is reciprocal and intimate. Not only does laser technology flourish by exploiting advances in each of these fields, it also contributes significantly to their growth.

3. SOME PRACTICAL LASER SYSTEMS

Let us now look at some important categories of practical laser systems.

Solid state lasers use as their active media solid crystals doped with impurity ions. It is the energy levels of the impurity ions that are

involved in the laser action. As mentioned earlier, the first successful laser was the ruby laser which is one example of a solid state laser. The chemical composition of ruby is Al_2O_3 with 0.05% by weight of Cr_2O_3 as an impurity. The aluminium and oxygen are inert and it is the chromium ions Cr^{+3} which participate in laser action. The density of chromium ions is $1.62 \times 10^{19}/cm^3$. The pumping is done optically by discharging a charged capacitor through a flash lamp giving a laser pulse output at a wavelength of 6943 Å. A high pressure mercury arc lamp is often used since its output matches the ruby absorption bands quite well. Continuous wave operation is more difficult because of the higher pumping requirements and the resulting high temperatures generated within the crystal. In the early 70's large deposits of ruby were discovered in Taita Hills and I had hoped Kenya would become a great ruby laser manufacturing country. I said to myself, "Otieno, this is your chance of becoming rich!". But alas! The cut-throat methods employed by both local and foreign prospectors were frightening and my hope of becoming a millionaire was never to materialise.

A more useful solid state laser is the Nd: YAG laser. Nd^{+3} ions are used to dope yttrium aluminium garnet $Y_3Al_5O_{12}$ or YAG with a maximum doping level of about 1.5%. The pumping can be done by a flashtube and average powers of 2×10^4 W have been achieved at pulse repetition frequencies of up to 300 Hz. Indeed it is possible to compress total pulse energy by a technique known as Q-switching to obtain powers of up to 10^8 Watts. The Nd: YAG laser, which operates at a wavelength of 1.06 μm can also give a continuous wave CW output when pumped by a tungsten filament or the quartz-halogen lamp. CW outputs of several hundreds watts are possible necessitating water cooling of the laser rod since the efficiency of laser ranging from 0.1% to 2% are very low.

In Nd: Glass lasers, glass replaces YAG and much larger doping levels by Nd^{+3} ions (up to 6%) are possible. Their overall power efficiencies are also high (upto 5%). Lasing at 1.06 μm the Nd: Glass laser is the most advanced high-power pulsed laser in which peak powers of several terawatts have been reported.

Another solid state laser, the alexandrite laser (Cr^{+3}: Be Al_2O_4) was first operated in 1973 at a wavelength of 680 nm. It was later discovered that the lasing wavelength could be varied over the range 700-820 nm, thus making it a tunable laser.

Another important class of lasers which have important applications is that of semiconductor lasers. Although made from solid materials such as GaAs, semiconductor lasers differ considerably both in respect of the energy structures and pumping mechanisms, from the doped insulator types we have just considered. Semiconductor laser based on GaAs are efficient low power tunable compact (extremely small size) and very reliable devices emitting radiation in the range of 0.3 - 30 μm. Their pumping is achieved by a direct application of current across a pn junction from which laser action takes place. The laser output is proportional to the current flowing across the junction and this lends itself to certain useful applications, especially in communications as we shall see later.

In gas lasers, certain gases are used as the active laser media. The gas, at fairly low pressure, is contained within a glass discharge tube with anode and cathode at either end. The cavity mirrors one outside the tube and a few dc kilovolts applied across the tube initiate a gas discharge. The free electrons in the discharge are accelerated by the electric field and as they travel out towards the anode they collide with neutral atoms or ions, thereby giving up some or all their energy to them, thus "pumping" the atoms or ions to excited states.

It is convenient to classify gas lasers into three broad categories of atomic, ionic and molecular depending on whether the lasing transition takes place between the energy levels of atoms, ions or molecules. By far the commonest atomic laser (indeed the first ever gas laser) is the He-Ne laser which gives as its output the familiar CW red light operating at 6328_ which is to be found in most physics

and electrical engineering laboratories in universities or even schools. Its active medium is a mixture of He and Ne in the ratio of ten parts of He to one part of Ne. The mixture is contained in a narrow tube of a few millimetres in diameter and from 0.1 m to one 1 m long at a pressure of 10 torr (mm of mercury). Transition of the Ne atom give rise to laser output at wavelength of 3.39 μm, 1.15 μm (infra red) and 6328 Å and 5435 Å (visible). Quarter wavelength coated mirrors can be used to select the required wavelength output.

Although the He-Ne laser gives a low power output ranging typically from 0.5 to 10 mW, it is useful because of its monochromatism and excellent beam quality and also because of the high directivity of its output. A He-Ne laser beam 5 cm in diameter will spread by only 0.5 cm in 300 metres. t is also light and portable.

In 1971 Peter Smith, a scientist at Bell Laboratories in New Jersey, announced to the world the invention of the first He-Ne waveguide laser. This was after he had spent his sabbatical at Berkeley and we had worked together on the project. At best I should have been a co-author of that paper which appeared in Applied Physics Letters. He was however decent enough to acknowledge my contribution to that invention in the article.

Basically the wave guide laser we invented differed from a conventional one in that the He-Ne gas was confined in a thin bore capillary tube with an internal diameter of the order of 0.017 of an inch. As a result the mode of propagation was a guided wave by reflections by the walls of the capillary tube.

A good example of an ion gas laser is the argon ion laser where the transitions are between the electronic energy levels of an ion. The excitation takes place in a gas discharge. The argon ion laser has more power than the He-Ne laser and operates at 488 nm (blue) and 514.5nm (yellow) in CW mode or pulsed. The blue line is useful for medical applications.

The best known molecular gas laser is the carbon dioxide which is the most important laser of its class in terms of technological applications. It is the most powerful CW laser giving power outputs of up to several hundred kilowatts thus making possible its use in applications such as welding and cutting of steel, pattern cutting, weaponry and laser fusion. The lasing transition at a wavelength of 10.6 μm involves the energy levels resulting from the quantization of the vibrational and rational energy of the Co_2 molecule. In a Co_2 laser nitrogen is often mixed with Co_2 in comparable ratios to facilitate efficient pumping of the Co_2 molecule. Co_2 lasers can operate in pulsed mode giving out short, high energy pulses. Other important gas lasers include chemical lasers and "excimer" lasers.

In chemical lasers, laser action is achieved by mixing two or more energetic gaseous elements. Unlike other kinds of lasers which need a "pump" to produce population inversion, in chemical lasers the working medium itself has enough chemical energy to trigger laser action. A popular reaction for the chemical laser is that between hydrogen and fluorine. If both are present only in their molecular form then no reaction takes place; however if by some means single atoms of either species can be generated the resulting chemical reaction produces laser action at a variety of wavelengths from 2.5 to 3.4 μm. Once laser action has been produced the batch of chemicals cannot easily be made to lase again; the chemical laser must be constantly supplied with fresh chemicals. Chemical lasers are extremely efficient, typically converting 20% or more of their chemical energy into laser light.

One of the more recent developments is the excimer laser, which lies somewhere between an electrically pumped laser and a chemical laser. Excimer lasers are based on principles that most chemists would have considered impossible a generation ago. While lasers in general owe their existence to the quantum revolution that shook physics in the first half of the twentieth century, the excimer laser owes its existence to a smaller revolution that rattled the world of chemistry two years after the first laser was built. It used to be an axiom of chemistry that the noble gases, that is (in order of their increasing atom weights) Helium, Neon, Argon, Krypton, Xenon and the radioactive Radon,

were chemically inert, until 1962 when Neil Bartlet, a British chemist, showed that Xenon could link chemically with fluorine which is one of the most active elements of them all. In an excimer laser, an electric discharge is passed through a mixture of a noble gas and a halogen (chlorine, fluorine, bromine or iodine). The two gaseous elements combine to form an excimer which is a compound that can exist only in the excited state. The word "excimer" is a contraction of excited dimer. The electrical pump thus induces a chemical combination that yields an excited molecule, an excimer.

The excimer can be stimulated to emit a photon, thus causing laser action. A comparatively large number of excimer lasers have been developed covering the wavelength range 0.12 μm - 0.5 μm. Some of these are quite efficient, up to 15%. Peak powers of up to 1 J with average powers os some 200 W can be obtained. Such high-power pulses are particularly useful as pump sources for dye lasers, in fusion systems and for photolithography.

Liquid dye lasers are made by dissolving certain organic dyes in suitable liquid solvents resulting in strongly fluorescent solutions. Liquids have several advantages over both solids and gases for use as laser gain media. Like gases, they are much more homogeneous than solids. Besides they have a high density of active atoms than do gases. Liquid dyes absorb radiation over a certain band of wavelengths and subsequently emit over another band situated at a somewhat higher band of wavelengths. A typical example of a dye laser medium is rhodamine 6G in ethanol. Dye lasers emit tunable outputs 0.3 - 3.0 μm with extremely narrow linewidths and are used in high resolution spectroscopy. They can be pumped using flashtubes but more often they are pumped by other lasers such as argon ion laser light.

These are but a few of the types of lasers that are in operation. Future lasers include the X-ray laser which it is predicted will self-destruct as soon as it starts to lase owing to the high energy it will contain. A more promising future laser is the free electron laser that promises the sort of characteristics laser users have dreamed of: tunability over a wide range (from the extreme ultraviolet to millimeter wavelength) with high power, high efficiency and potentially low cost.

Table 1 summarises some of the laser systems that have been developed and are widely used. It is by no means exhaustive because a large number of other lasers made of other materials do exist. It was reported, for instance, that a high school boy living in the slums of Boston picked up a discarded fluorescent tube and made a laser out of it. His lasing medium was his own breath with which he filled the tube!

Table 1 Important Laser Systems in Use Today

Laser	Wavelength	Comments
Ruby	694.3 nm	First ever laser used as pulsed source of high peak power.
Nd:YAG	1.064 µm	Used extensively for material processing, ranging and mechanical applications; also as an oscillator lin high power systems.
Nd: Glass	1.064 µm	Most advanced high-power pulsed laser;1.054 µm peak power several terrawatts, used in fusion studies.l
He:Ne	632.8 nm 1.115 µm 3.39 µm	First gas laser. Low power <10mW frequency standard and in holography
Argon-ion	0.4880 µm 0.5145 µm	Most powerful C.W. visible lasers. Can also be pulsed to give more power output. Used to pump dye lasers and in medical research and printing applications.
Carbon dioxide	10.6 µm	Most powerful C.W. laser with power output of several hundred kilowatts. Used in materials processing; low power (<100W) lasers used in medical applications.
Semi conductor	0.3 - 30µm	Efficient, low power turnable compact devices used in communications, optical readout and high-resolution spectroscopy.

4. LASERS IN SCIENTIFIC RESEARCH

As mentioned earlier there has been a remarkable intimacy between the development of the laser and the advances in other branches of science and technology each contributing to the growth of the other and it is therefore not surprising that the most important beneficiaries of the properties of the laser are scientists themselves. Because of its monochromatism, frequency stabilised laser radiation provides frequency and length standards and the status of the glorified standard yard, wherever it used to be hidden in a highly controlled environment, has been reduced to a historical curiosity. Using lasers, scientists have "isolated" atoms and have been able to identify impurities at the level of one part in more than a billion billion. In basic research, the vast field of non-linear optics has been opened up by the use of the laser which has allowed the generation of vacuum ultraviolet radiation as short as 35.5 nm in wavelength. Non-linear optical processes have also allowed the study of ultra-fast physical, chemical and biological processes which occur in the picosecond and sub-picosecond regimes. Lasers are used as sources in Raman spectrometers and through stimulated Raman effect a host of wavelengths have been generated. Laser spectroscopy has opened up the possibility of accurately studying the Doppler-broadened linewidths of gas lasers by using molecular beam spectroscopy, non linear saturation spectroscopy and two photon spectroscopy. One possible large-scale commercial application of what is essentially a spectroscopic technique is that of laser enrichment of uranium. Uranium 235 which is used in nuclear power industry is only 0.7% of naturally occurring uranium which is far less than the needed 3%. The usual enrichment technique of gaseous diffusion is expensive and laser enrichment promises a considerable reduction both in capital and running costs. A three-step transition process using dye amplifiers pumped by copper or gold lasers results in the preferential ionization or selective excitation of uranium 235 atoms which may then be separated out using an electrostatic field.

In starting self sustaining thermonuclear reactions for power generation, it is necessary to have plasma temperatures greater than 5 x 10^8 K with densities greater than 10^{14} cm^{-3} while confining the plasma. Most major laboratories have successfully converted their high power Nd:glass laser beams to double, triple, and quadruple frequencies and employed the shorter wavelengths in laser fusion studies. In a fusion reaction, energetic neutrons are created and neutron numbers in excess of 10^9 per laser pulse have been observed but this is considerably lower than that required to reach "scientific breakeven", which is defined as the level at which the thermonuclear energy generated equals the laser energy input. Energy breakeven should be achieved in the very near future. There is a host of other scientific applications of lasers which exploit their very special properties.

5. LASERS IN ENGINEERING

Perhaps the simplest engineering applications of lasers such as the He-Ne laser exploit their high collimation, or directivity, resulting from their spatial coherence, which enables the use of such visible light as a reference line which can be used for tunnel drilling, positioning objects, surveying guidance of equipment in construction and defining straight lines for civil engineering projects such as pipeline construction. Other alignment functions include the assembly of large structures such as aircraft and ships, the erection of tall buildings and the alignment of high- power lasers which operate in the invisible infra-red.

The temporal coherence of the output of a He-Ne laser has made it possible to extend and precision of the measurement of distance based on interferometry to ranges of upto 10 metres with an accuracy of one part in 10^7. For larger distances, laser beam modulation telemetry or time-of-flight methods are used with remarkable accuracies.

Many engineering applications of lasers arise from their ability to deliver energy in a highly controlled manner, providing unprecedented accuracy and precision in heat treatment. It is of course perfectly possible to weld, cut and drill without having to resort to such technically advanced and expensive solution as the laser. However, lasers do offer a number of advantages when compared with the more conventional techniques. For example: Laser radiation is a very "clean" form of energy that no contaminating materials need come into contact with the work piece because the working atmosphere can be controlled to suit a particular task. A laser beam by having high spatial coherence can be focused to a very small spot having dimensions of the order of its wavelength. Very intense local heating can therefore be achieved without affecting neighbouring areas.

It is comparatively easy to control the beam irradiance of a laser beam. A laser beam can be readily directed into relatively inaccessible places; it can pass through transparent windows and be directed round sharp corners.

Most of the laser energy is deposited very near the surface of the target, thus enabling shallow surface regions to be treated without necessarily affecting the bulk.

The most commonly used lasers for materials processing are the Nd:YAG and Co_2 lasers with the latter perhaps being the more versatile because it is available with a wide range of output powers and reasonable cost. The Nd:YAG is more useful in areas of application where shorter operating wavelengths are suitable.

Surface hardening was one of the first successful applications of high power lasers in materials processing industry. Surface hardening of ferrous materials involves heating to above a critical temperature followed by a rapid cooling, a process usually described as quenching. Surface hardening may be achieved by scanning a high power laser beam over the surface to be treated to achieve the required heating.

In microelectronics, one of the main areas of semiconductor processing is the annealing of ion implant damage in silicon. Ion implantation is the technique of precision doping of semiconductors, that is, the controlled introduction into pure silicon of relatively small concentrations of impurity ions which affect its electrical properties. The usual method of doping is by diffusing impurity atoms at relatively high temperatures by exposing the semiconductor surface to a gas containing the impurity atoms. However, in ion implantation the surface of the semiconductor is physically bombarded with energetic impurity ions, and the Kinetic energy of the ions controls very pricely the depth over which doping takes place. But this method has a major drawback in that the physical impact of the ions on the surface creates an amorphous, that is, noncrystalline layer a few hundred nanometres thick on the semiconductor surface. Since the dopants are only effective when they are in a crystalline environment the semiconductor surface must be recrystallised. This may be achieved by heating it in a furnace for at least 30 minutes at a

temperature of $1000^{0}C$. During this process of annealing, some of the impurities can diffuse appreciable distances thus defeating the whole objective of precise doping. This problem has been neatly overcome by laser heating. In laser annealing, the surface allows recrystallisation to occur relatively quickly thereby allowing the dopant ions little time in which to diffuse. When pulsed lasers are used for annealing ion implanted semiconductors, the surface actually melts and then recrystallizes, a process described as liquid phase epitaxy. On the other hand, when C.W. lasers are used no melting takes place but nevertheless the surface structure is restored, this process being described as solid phase epitaxy. One advantage of laser annealing is that by varying the laser power, its wavelength and its interaction time, the doping depth and profile can be accurately controlled.

Lasers have been successfully used to etch out organic photoresisting materials by laser ablation. Since the process does not require wet chemistry for pattern development it is much faster and anisotropic.

High power Co2 lasers are finding increasing use in welding which basically is a process in which two metals (which may be the same or dissimilar) are placed in contact and the region around the contact heated until the metals melt and fuse together. Laser welding has to compete with well established techniques such as soldering, arc welding, resistance welding and electron beam welding. It has, however, a number of advantages: there is no physical contact with external components; the heating is highly localized; dissimilar metals can be welded; and welding can be carried out in a controlled atmosphere with the work piece sealed off if necessary within optically transparent materials.

The ability to focus a laser beam down to an area only a few microns across and the ease with which it can be directed and controlled has led to the use of lasers in microwelding. This has been used in precision soldering of integrated circuit leads and other minute metal contacts such as are found in microelectronics. In this area the Nd:YAG laser has some advantages over the Co_2 laser because the

1.06µm of the former is much more readily absorbed by metals than by insulating materials.

Lasers are also used in cutting materials. The aim is to vaporise the material as quickly as possible to produce as narrow heat-affected zone as possible with minimum distortion of the workpiece. Most materials can be readily cut using a Co_2 laser with the exception of those such as brass, copper and aluminium which have high reflectance at 10.6µm and also high thermal conductivities. However, since the reflectances of these materials are lower at 1.06µm, Nd:YAG lasers can be used instead.

Lasers have several advantages in the cutting of non-metals. In the slitting of paper using lasers, for example, the debris problem normally associated with mechanical techniques is eliminated. Nylon seat belt material also may be cut by lasers cleanly and the edges sealed with no burning taking place. Foam rubber may also be cut by lasers without discolouration.

The ability of lasers to selectively vaporise small areas of material have been exploited in micromachining. One such example is in the trimming of resistors. Resistors are made by a wide variety of techniques but often consist of a thin film of conductive material (for example, nicrome, tin oxide or tantalum nitride) deposited on an insulating substrate (generally alumina, Al_2O_3) between the two electrodes. During manufacture, the films may not have the exact required resistance or range of resistances and may therefore need trimming. This can be achieved by using a laser to vaporise small areas of the resistor to adjust its resistance even when it is in position in an integrated circuit.

In addition to resistor trimming, lasers have also been used to form capacitors and process components on a silicon substrate. One of the very first industrial uses of the laser was reported in 1965 when a diamond die for drawing wire was drilled using a pulsed ruby laser. A hole 4.7 mm in diameter and 2 mm deep was made in

approximately 15 minutes as compared to the mechanical process that had previously taken 24 hours to drill a similar hole. More recently cooling holes have been drilled in an aircraft engine turbine blade using a pulsed Nd:YAG laser. Holes are readily drilled in non-metallic materials such as rubber and paper using lasers with the advantage of there being no distortions during the hole formation unlike the case where conventional mechanical techniques are employed.

In other engineering applications, lasers are used as a tool for stress and vibration analysis as well as for detection of defects and deformations. This application, based on holography, exploits the coherent nature of lasers, that is, the well defined manner with which the phase of the associated electric and magnetic fields varies over the beam cross-section at a given instant of time and also with time at a given position. Coherence of laser light has made possible the practical realization of three dimensional photography, or holography, invented by Denis Gabor at Imperial College, London in 1948.

When light is scattered by an object, information about the depth is contained in the phase of the generated wavefront. In ordinary photography where only the intensity is recorded, this information is lost. In holography on the other hand the wavefront of the scattered light is made to interfere with another coherent "reference beam" and the resulting interference pattern which contains information about both the amplitude and the phase is recorded. On illumination of the hologram with coherent light the whole wavefront is reconstructed and a three dimensional image can be formed. While holography has potential applications in areas such as microscopy, information storage and display, the most promising area is in non-destructing testing employing interferometric techniques. In real-time interferometry, the wavefront of light from, say, an object under stress is made to superimpose with the wavefront obtained from its hologram recorded under no load conditions. The resulting interference pattern gives information about the deformation occurring in the object as it is stressed. In double exposure interferometry, holograms of the object at two instances are recorded on one photographic plate. The resulting interference pattern can give information about deformation as well as help in locating weak or defective areas. These techniques are used for example, in testing of tyres during manufacture, measuring deformation of moulds and in the testing of laminates and composite structures such as clutch plates, jet engine fan-blades, compressor blades and the like. In time-average interferometry a hologram of a vibrating object is recorded using exposure times much longer than the period of vibrations. The resulting interference pattern can give information about the amplitude of vibration with high precision. This technique is very useful in vibration analysis of complex structures and is presently being widely employed for the study of engine vibrations in the aircraft and automobile industries.

6. LASERS IN MEDICINE

There are three main application areas in which lasers have successfully established themselves in medicine. These are in surgery, in ophthalmology and in dermatology. In surgery, the laser beam is used as the scalpel or the cutting tool and the Co_2 laser has proved to be the most successful, although Nd:YAG lasers can also be used. The 10.6µm output of the Co_2 laser is strongly absorbed by the water molecules present in tissue and the subsequent evaporation of the water leads to the physical removal of the tissue. The application of lasers in surgery has several advantages over mechanical cutting: the laser beam can be positioned and controlled with high accuracy, relatively inaccessible regions can be reached, limited damage is caused to adjacent tissue and the laser beam has a cauterizing effect on nearby blood vessels which reduces bleeding. The essential requirement for laser surgery is for a maneuverable optical delivery system. This is achieved by using flexible optical fibres for the Nd:YAG laser and in the case of Co_2 (for which no suitable fibres exist as yet for 10.6 µm radiation) the beam is passed

down the centre of a series of articulated metal-tubes with mirrors at the junctions.

In ophthalmology, lasers have been successfully used to reattach detached retinas for many years now. The ruby laser was the first to be used for such operations although use of the green output from argon ion lasers is now more widespread. The radiation is strongly absorbed by red blood cells and the resulting thermal effects enable the retina to be reattached. In other applications in ophthalmology, it may be necessary to operate on an optically transparent medium. In these cases, sufficiently high laser-light irradiances are used. The associated electric fields cause "dielectric breakdown" in the desired region. This causes electrons to be stripped from the atoms present and a plasma is formed. This in turn generates a high-pressure shock wave which expands outward like a miniature explosion and vaporizes the surrounding medium.

Glaucoma is a disease of the eye which is caused by raised intraocular pressure in which the aqueous fluid cannot drain and the chronic form is insidious and causes progressive loss of vision by pressure on the optic nerve. Lasers have very recently been successfully used by British opthamologists to puncture tiny holes in the eye for draining the fluid leading to a full restoration of vision. The whole operation can be done within a few minutes. Some disfiguring skin conditions can be successfully treated with lasers. When these cover large areas, it is difficult to treat them using conventional surgery. However, controlled exposure of such skin to an argon ion laser beam can cause a permanent bleaching of the affected areas.

Photoradiation therapy is a cancer treatment method which uses lasers. The patient is injected with a dye substance called HpD. After a few days,.the dye accumulates in the cancerous tissue while normal tissue excretes it. Laser light from a dye laser pumped with an argon ion laser and operating at 630 nm wavelength is applied to the HpD which undergoes a series of photochemical reactions resulting in the production of a chemical that destroys the cancerous tissue.

One promising future application of lasers in medicine is in the treatment of coronary artery blockages using lasers. Medical endoscopes are being developed consisting one or more bundles of optical fibres. Optical fibres are optical waveguides which are used to lead light to any required region. These are introduced into the artery using catheters. One bundle, the sensor, transmits the image of the blockage to a monitor screen. Another fibre bundle sends laser energy to the blockage and evaporates it. Similar techniques can be used to remove blood clots. Thus one endoscope, after insertion, can do three functions, that is, imaging, diagnosis and therapy. The ability to view the blockage of fatty material plaque, greatly reduces the risk of accidentally burning a hole in the artery wall. This treatment is very simple compared to the complicated open-heart bypass surgery. A fibre endoscope can reach regions where a scalpel cannot. Examples of devices performing specific functions include the colonscope (for colonic examination and detection of polyps) and the angioscope for examining coronary arteries and for removing obstructions.

The light from a laser can also protect blood banks from deadly viruses, including the HIV virus that causes AIDS. A team of researchers in Texas, U.S.A. have developed a method for heating stored blood with a light absorbing dye, and then exposing the blood to a low intensity laser beam. They claim a 100 percent kill rate for viruses that cause measles, herpes simplex type 1, AIDS and others. This does not mean that lasers can be used to cure AIDS in infected humans, so please continue to be vigilant. Within the rapidly growing field of biomedical engineering, the laser is poised to play a vital role in medicine.

7. LASERS IN THE INFORMATION AGE

Light as the basis of a communication system has been used from time immemorial, the earliest recorded example being by the Greeks in the 8th Century BC using fire signals. Flag signals as used by

Boy Scouts and even hand gestures are a good example of light-based communications. Some languages like Italian or to some extent Kiswahili lose half their meaning if the spoken word is not accompanied by the appropriate dramatic gestures. The early systems used relay stations to enable them to cover long distances but the transmission of complex messages proved to be slow and cumbersome and the systems were easily disrupted by adverse weather conditions and were useless at night. It was thus generally more reliable to send messages by courier using roads.

Little further progress in optical communication was made until 1880 when Alexander Graham Bell, the inventor of the telephone, devised the photophone which employed a diaphragm to modulate sunlight and was capable of speech transmission over 200m. Unfortunately, it could not compete with electrical telegraph invented by Morse earlier in 1838, and so it was destined to remain no more than a laboratory curiosity.

In 1895 Marconi demonstrated the first free space communication using long radio waves. Since then an ever increasing part of the electromagnetic spectrum has been used for communication purpose. The amount of information that can be transmitted increases with increasing frequency of the carrier wave.

Since World War II most communication, audio and video, has been based on the use of microwaves which span a frequency spectrum 1 GHz to 100 GHz. Since optical wave frequency is 100,000 times higher than that of microwaves, the use of light for communication implies an enormous information carrying capacity. In addition, optical communication is free from "cross talk" and is immune from electromagnetic interference.

The role of lasers in optical communication systems is to provide the source of radiation. Although light emitting diodes LED's emitting incoherent light provide a much cheaper alternative as radiation sources, lasers by emitting coherent light have the advantage of the ease with which their beams can be coupled into optical fibres which results in achieving higher data rates. Also in principle, it is possible in future to employ heterodyne detection by employing coherent laser beams in communication.

The recent advances in semiconductor diode lasers, in optical fibre communications and in computers have been so successful that mankind is on the brink of being ushered into a new industrial era, the so called "information age", whose main features are storage, processing and communication of information. Of these to date communication is the most developed.

Laser beam propagation through the atmosphere is seriously affected by weather conditions such as fog, rain and clouds which cause severe attenuation rendering it unsuitable for communication. In outer space, however, the absence of an atmosphere offers an excellent medium for line-of-sight communication between satellites. In this case, the laser beam has two advantages over the microwave radiation presently in use. The laser beam spreads far less than microwaves resulting in a higher communication efficiency and also it is capable of much higher data transmission rates.

Terrestrial optical communication received a major boost with the arrival on the scene of optical fibres capable of transmitting laser beams. Kao and Hockman, working at the Standard Telecommunications Laboratories in Harlow, England, were the first to realise that a glass fibre could guide light in 1966. An optical fibre is a thread-like, flexible structure thinner than a human hair made from glass materials having a central core and a surrounding cladding. The materials are chosen such that the core has a higher refractive index than the cladding and as a result a light beam launched at one end of the fibre always remains confined to the core and travels along the fibre, even around curves. Fabrication technology of optical fibres has undergone dramatic improvement in the last couple of decades. While with the earlier fibres light intensity dropped to as low as 1% of their initial values after travelling along only 20 m of fibre, the present day fibres retain more than 98% of the initial signal even after a length of 1 km.

Continued development is expected to further reduce the losses by a factor of between 10 and 100. The extremely low losses imply that a signal can be transmitted over a distance of over 100 km without the need to boost it. By contrast, transmission at microwaves through coaxial cables requires regeneration after every few kilometres.

The vast improvement of the semiconductor diode laser in the 1970's has produced reliable lasers with extremely high speed, up to several gigabits per second. The advantage of fast modulation can be appreciated by noting that at one gigabit per second the entire contents of the Encyclopaedia Britannica can be transmitted in less than five seconds.

The high data transmission capability of optical communication system combining lasers and optical fibres makes them ideally suited for handling data traffic between a computer's central processing unit and various peripherals, as well as linking different computers to form a network. In public telecommunications, optical fibres are being increasingly used for connecting different digital exchanges in metropolitan areas and pulses of laser light are rapidly replacing electrical currents. The race between electrons and photons in communications is being won by photons.

The compact nature of optical fibres poses fewer problems in laying cables in underground conduits. The KPTC's Nairobi Central Exchange, which is digital, employs fibre optics in some of its circuits, a very encouraging trend indeed.

Optical communications has also proved to be competitive for intercity and international long distance links. As an example, the eighth transatlantic cable, TAT-8, laid by AT & T to link U.S.A. and Western Europe, is the first to use fibre optics. It can carry 37,800 simultaneous telephone calls or a mixture of voice, video and computer data four times the capacity of its predecessor TAT-7 which employed copper cables. An all optical repeaterless link will be laid across the Atlantic in 1996 using in-line optical amplifiers at 1.535 μm carrier.

It may be that the need for communication satellites in space will decrease in future as more fibre-optic links are established world wide. At present, however, optical fibres are playing a complementary role, carrying signals from the city based terminals to an antenna in a suitable remote location for beaming data to the satellite. In future the real impact of optical communications will not be in providing a cheaper alternative to microwave based systems, but in making entirely new applications possible. Communication specialists are already planning to establish Integrated Services Digital Networks. Each Integrated Services Digital Network, or ISDN in short, will form a single unified communication network transmission of audio, video and computer data. Such a network, employing optical fibres, is expected to tie together every business, household and computer within a country and eventually throughout the world. The resulting communication device will therefore be capable of tapping into the Library of Congress from Nairobi as easily as it will be able to obtain the weather forecast of any part of the world or to connect one with a friend half-way around the world for a face to face video conversation.

Ultimately the communication device will be small enough to carry around, even to wear on one's wrist. In this respect, optical communications could really be said to be ushering in a new age, the Information Age.

Application of computers is now becoming quite widespread even in many developing countries. The laser has made substantial impact on all the main aspects of modern computers, that is, interfacing to users, data storage, and processing. The slowest link in the information chain from the computer to the user is often the printer and this is one area where lasers have made a great deal of difference. In a laser printer, the beam charges a photoconductive surface to which electrically charged ink (toner) particles stick. To form a character, the laser beam is deflected by a computer controlled acousto-optic deflector onto the photoconductive surface. Laser printers operate at much higher speeds (up to a hundred pages per minute) and offer a higher quality than impact printers and fast

approaching the latter in terms of cost. Since no hardware characters ar involved, there is no wear and tear and the same printer can be used for all scripts - a great advantage in any multilingual society. The very high resolution afforded by a laser printer allows one to print diagrams and sketches and has lead to the now popular "desk-top publishing". The laser is also used in reading printed information the most common example being the bar code scanner used in supermarkets for billing and automatic stock control.

Laser light can be used to store information as well. Optical information storage systems are among us in everyday lives. Compact disc (CD) records are made and then played back with laser beams as are video discs - discs that have recorded motion pictures for viewing on home television sets. A laser beam, focussed down to an extremely small spot, burns tiny holes into a light sensitive film coated onto a disc which is spun at a high speed. The laser is operated in extremely short pulses and the holes burned onto the disc in a pattern, like a sort of microminiaturized braille, that can be read with another laser. Compact discs records and video discs have already set new standards of fidelity and compactness in the world of music and video films.

Optical discs are being developed to store data efficiently and compactly for hospitals, businesses and other organisations that generate huge quantities of files. Once stored, the information can be retrieved rapidly on a hard copy printed form or on a television monitor. In future libraries will soon resemble computer centres rather than bookshops.

Perhaps farthest in the future but of the greatest importance is the prospect of using lasers for fully optical computing. Computers that store information in holograms and use thumb-nail size diode lasers could be made much smaller and faster than today's; electronic computers. The hard disc of today's electronic computers stores information in form of tiny magnetic fields impressed on the disc. They can pack the equivalent of 600 typewritten pages into an area of a postage stamp.

A single hologram of size one square centimeter, a little more than half the size of a postage stamp, could contain as many data bits as 14 cubic feet of ordinary computer memory storage. The next time you are in your kitchen, hold a postage stamp along side your refrigerator to get the feel of the tremendous advance that optical computer can offer.

Optical computers will be much faster machines because light beams travel much faster than electrons and do not generate as much heat as electrical devices. Photonic computers can be smaller, faster and more reliable than their electronic predecessors. Holographic memories will bring the most powerful computers down to the size of the palm. Because of the enormous information handling capacity, photonic computers might be built large enough to rival the information capacity of the human brain. The first truly intelligent computer may one day work on beams of laser light, but long before that day dawns, beams of light from diode lasers will begin to replace electric currents inside computers.

8. LASER WEAPONRY

H. G. Wells, that great master of science fiction, in his book The War of the Worlds published in 1898, described the heat-ray weapon used by Martians against helpless Earthlings as follows:

"Suddenly there was a flash of light .... at the same time a faint hissing sound became audible .... Forthwith flashes of actual flame .... sprang from the group of men. It was as if some invisible jet impinged upon them and flashed into white flame. It was as if each man was suddenly and momentarily turned to fire .... it was sweeping round swiftly and steadily, this flaming death, this invisible, inevitable sword of heat".

Fans of James Bond 007 are also familiar with his lethal ray gun. Although such a deadly weapon still belongs to the realm of science fiction, today we call it a laser.

The outputs of the highest power lasers are now such that their use as weapons can be contemplated. The most fascinating possibility would be to use powerful lasers, based in orbiting satellites, to destroy enemy ballistic missiles bearing hydrogen bomb warheads. In march 1983 when I was inside Kamiti, a prison warden (who shall remain nameless for his own safety) smuggled a newspaper into my cold cell and in it I was able to read that President Reagan of the United States had announced the Strategic Defence Initiative Programme which the media immediately dubbed "Star Wars". You can bet the laser is an essential component of "Star Wars".

The controversial Edward Teller, father of the American hydrogen bomb, foresees X-ray lasers, which he calls third generation nuclear devices (after fission and fusion bombs respectively), as being used in space as part of "Star Wars" type of strategic defence system. The X-ray laser having been pumped by the energy of a nuclear explosion and before it is itself destroyed by the blast would deliver an intense beam of X-ray at an on-coming ballistic missile thereby destroying it.

Today, however, the laser is not used as a deadly ray gun in war but in more subtle ways. For example, in the recent Gulf war, variously nicknamed the "Mother-of-all-battles" or "Operation Desert Storm" depending on which side you supported, laser beams were used to target heavy "smart bombs" onto Saddam Hussein's installations with unprecedented precision. We watched it all happen on CNN.

9. EPILOGUE

Important laser applications have been highlighted in this lecture: applications in engineering, manufacturing and industry; in scientific research and measurements; in medicine and in weaponry; in communications and informatics. But there are many other applications both current and potential because when it comes to applications of lasers the sky is the limit.

The laser is a triumph of the quantum theory of light, a tribute to great scientists like Planck, Bohr and Schroedinger. Newton and Maxwell, not even Einstein could have invented the laser; they simply did not know enough about the nature of light although Einstein might have done it if he had not rejected the quantum theory!

Today, we know a great deal more about the nature of light and its interaction with matter to the extent that we can manipulate atoms, so to speak, to give out useful energy in form of laser light. The laser has become a revolutionary and versatile tool and, with its unlimited range of applications, is bound to change our lives a great deal. And so the inevitable question is posed: what is in it for us in the developing world, in Africa? Are we going as usual to take a back seat and watch while a new age of scientific revolution is unfolding to mankind right before our very eyes?

It may be that starting a large scale manufacture of lasers needs not only massive financial investment but also a fairly sophisticated industrial base. But my contention is that whatever the cost, developing countries should not be left behind in laser technology. We should encourage the teaching and development of laser technology. The laser is a very effective tool for spreading the culture of high precision - a hallmark of modern technology. Let us use lasers in our factories to cut metal and in our operating theatres as the scalpel and to look into the human body without cutting it open. Let us use lasers in our communications networks if only because we are part of a world which is daily becoming more cosmopolitan. Let us use lasers in drilling straight tunnels, in aligning our roads and in

laying pipes. We can borrow a leaf from the Japanese who believe that "if you want a system to have an impact on industry, you must use it". Like the computer, the laser is a symbol and a tool of the twenty first century and it would be wise to become familiar and friendly with it.

It is indeed very exciting that today we are living at a time when mankind is on the verge of a new scientific revolution, laser revolution. It is just as if we were there in the beginning when according to the book of Genesis, God said, "**LET THERE BE LIGHT**". It seems to me that it will be quite appropriate when future generations one day, referring to this age, our age will add, "**AND THERE WAS LIGHT, LASER LIGHT**".

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