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(Projek IRPA 02-07-040-017)

APPLICATIONS OF LASERS AND ELECTRO-OPTICS

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ABSTRACT

Supported by the IRPA Programme on Laser Technology and Applications, many types of lasers have been designed, constructed and applied in various areas of science, medicine and industries. Amongst these lasers constructed were high power carbon dioxide lasers, rare gas halide excimer lasers, solid state Neodymium-YAG lasers, nitrogen lasers, flashlamp pumped dye lasers and nitrogen and excimer laser pumped dye lasers. These lasers and the associated electro-optics system, some with computer controlled, are designed and developed for the following areas of applications:

1. Industrial applications of high power carbon dioxide lasers for making of i.c. components and other materials processing purposes. Prototype operational systems have been developed.

2. Medical applications of lasers for cancer treatment using the technique of photodynamic therapy. A new and more effective treatment protocol has been proposed.

3. Agricultural applications of lasers in palm oil and palm fruit fluorescence diagnostic studies. Fruit ripeness signature has been developed and palm oil oxidation level were investigated.

4. Development of atmospheric pollution monitoring systems using laser lidar techniques. Laboratory scale systems were developed.

5. Other applications of lasers including laser holographic and interferometric methods for the non destructive testing of materials.

The activities of the group (from 1988-1990) have resulted in the submission of a patent for a laser device, publication of many research paper sin local and overseas journals and conference proceedings, completion of 1 Ph.D. dissertation and 6 M.Phil theses. Currently (1991), a total of 3 Ph.D., 6 M.Phil research programmes are involved in this research and development programme.

(Projek IRPA 02-07-04-017)

TEKNOLOGI DAN PENGGUNAAN LASER DAN ELEKTRO-OPTIK

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ABSTRAK

Untuk Program IRPA (Perindustrian) ke atas Laser Teknologi dan Penggunaannya, berbagai-bagai jenis laser telah direkabentukkan dan dipergunakan dalam pelbagai bidang seperti sains, perubatan dan perindustrian. Diantara laser-laser yang dibina adalah laser karbon dioksida tenaga tinggi, laser eksimer gas nadir halida, laser keadaan pepejal Neodymium-YAG, laser nitrogen, laser pencelup yang dipam oleh lampu suluh, laser pencelup yang dipam oleh laser nitrogen dan eksimer. Laser-laser tersebut dan juga rangkaian sistem elektro-optik, ada yang dikawal oleh komputer, adalah direka dan dikembangkan untuk penggunaan dalam bidang seperti dibawah:

1. Penggunaan perindustrian dengan laser karbon dioksida tenaga tinggi untuk menanda komponen i.c. dan lain-lain tujuan pemprosesan bahan-bahan. Sistem 'prototype' ini telah dikembangkan.

2. Penggunaan perubatan bagi laser untuk rawatan barah dengan menggunakan teknik terapi fotodinamik. Satu protokol baru yang lebih berkesan untuk rawatan barah telah dicadangkan

3. Penggunaan pertanian bagi laser dengan kaedah pengesanan fluorosens minyak kelapa sawit dan buah-buahan kelapa sawit. Kaedah penandaan kemasakan sesuatu buah dan takat keoksidaan minyak kelapa sawit telah disiasatkan.

4. Perkembangan sistem pengukuran pencemaran udara dengan menggunakan teknik laser lidar. Sistem-sistem makmal telah dikembangkan.

5. Lain-lain penggunaan laser termasuk laser holografi dan interferometri untuk ujian bahan-bahan tanpa-kemusnahan (Non-Destructive Testing).

Aktiviti-aktiviti kumpulan ini (1988-1990) telah menghasilkan penyerahan satu paten untuk sebuah alat laser, penerbitan banyak kertas-kerja penyelidikan di dalam jurnal-jurnal tempatan dan luar negeri dan juga dalam persidangan dan simposium, penyelesaian 1 disertasi Ph.D. (Doktor Falsafah) dan 6 tesis (M.Phil) Sarjana Falsafah. Pada masa ini (1991), sejumlah 3 Ph.D., 6 M.Phil program penyelidikan telah terlibat dalam penyelidikan dan perkembangan program ini.

1. INTRODUCTION

Under the Laser and Electro-Optics Technology and Applications Programme, advanced laser based methods and instrumentations have being developed for use in industries, medicine, agriculture, remote sensing and a few other areas. The development of such process controls and methods are essential as Malaysia strives to become technologically advanced.

Thus, in the development of such laser based instrumentations, many useful laser systems have been designed and developed. These range from the low power nitrogen gas discharge lasers for palm oil fluorescence studies to high power transverse electric excitation (TEA) carbon dioxide lasers for integrated circuit components marking. Other types of lasers such as the solid state and liquid dye lasers have also been designed and constructed. During this process of laser development, many important associated technologies in high voltage techniques, electronic switching methods, high vacuum techniques and the usage of optoelectronic devices have also been developed.

Amongst the applications of these lasers, the efficient marking of ic components using high power carbon dioxide lasers have been developed. Such laser markers are finding increasing usage in the electronics industry as alternative automated processing technique. Lasers are also used for materials processing including non-destructive testing (NDT) methods for metal fatique and fault analysis. For medical applications, a new and more effective procedure for cancer therapy has been proposed by the group. Rapid diagnostic methods have also been developed for palm fruit ripeness and palm oil oxidation level studies. Remote sensing methods for the measurement of atmospheric pollution have also been developed.

This paper outlines the progress achieved in the design and development of such lasers and the application of these lasers and electrooptic systems for different purposes. A perspective on the ongoing programme currently supported by the IRPA programme is also presented

2. LASER BASED APPLICATION SYSTEMS AND INSTRUMENTATION

For a laser based application system to be functional, many advanced instrumentation and techniques have to be developed. A schematic layout of the major components required for laser based application system is shown in Fig. 1. This consists firstly of a laser system with its associated high

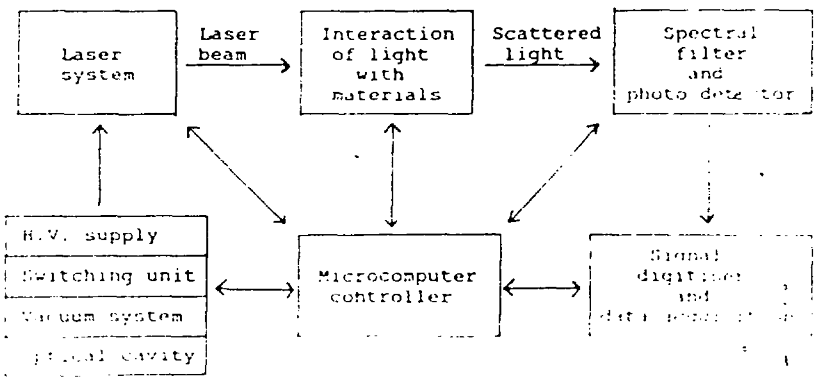


Fig. 1 Schematic diagram of a typical laser instrumentation

voltage and switching modules together with its vacuum system and optical cavity. The laser output is then directed and/or focussed to a target chamber where the specimen to be processed is placed for a specific laser light and materials interaction. The resulting scattering signals are then spectrally filtered and detected using appropriate photon detection system. The signals are then digitised and processed using on-line data acquisiton devices. Normally, an inexpensive and fairly powerful PC microcomputer system is used as the controller to ensure the integrated operation of the entire electro-optical system based on a laser for a specific application.

The development with respect to the different components of such a system and its applications are detailed further in the following sections.

2.1 DESIGN AND CONSTRUCTION OF LASER SYSTEMS

Many different types of lasers have been designed and developed. These included both gas discharge lasers, solid state lasers and liquid dye lasers.

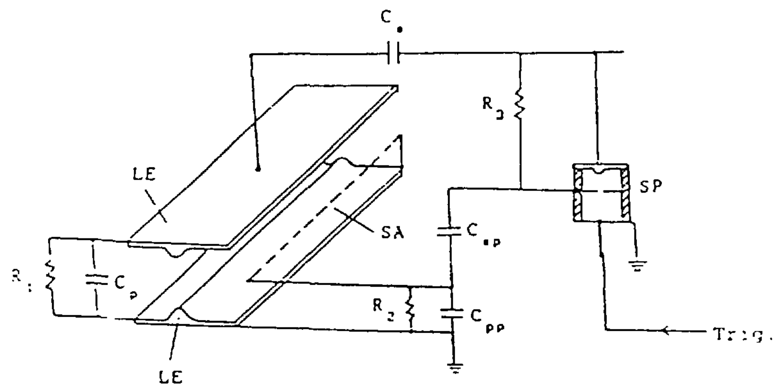
Table 1 summarises the types of lasers constructed thus far. The development of these lasers are further described in the following sections.

Table 1 List of Lasers Designated and Constructed

Laser	Design Type	Output	Reference
Gas Lasers			
1. N_2	Low pressure, Blumlein discharge	1 - 5 mJ 5 - 10 ns, pulse	1, 2, 3
2. TEA-CO_2	UV preionised	4 J/pulse	4
	small cavity	300 mJ/pulse	5, 6
3. Xe-Cl	UV presionised	60 mJ, 10 ns	7
4. He-N_2	High pressure, 2 stage Marx	337 nm - 4 mJ 428 nm - 1 mJ	13
5. CW-CO_2	Longitudinal, low pressure	10 W	[illegible]
	Transverse flow	-	
6. Metal Vapour Laser	CuBr, 5 kHz, small volume	3 W	9
	Gold, small volume	300 mW	10
Dye Lasers			
1. Flashlamp pumped dye laser	Coaxial, [illegible]	1 J	[illegible]
2. N_2 laser pumped dye laser	Oscillator amplifier simultaneous dual wavelength	500 uJ	[illegible]
Solid-State Laser			
1. Nd-Yad lasers	Compact, passive Q-switched	7 mJ, 10 ns	[illegible]
	Q switch	100 mJ, 20 ns	
2. Nd glass	Q switch	[illegible]	[illegible]

(1) **Nitrogen Lasers**

Nitrogen lasers are gas discharge lasers and are the simplest and the most inexpensive lasers to be constructed. These nitrogen lasers have, however, found many applications in different areas of science and industries. Fig. 2(a) shows a schematic diagram of a nitrogen laser. Basically, it consists of a high voltage supply source charging up an energy storage capacitor, C_s. On the switching of the spark gap device (S.G.), a rapid high current pulse is driven across the laser channel which when appropriately arranged will give rise to the stimulated emission of amplified radiation, i.e. a laser pulse. A cross section of a simple nitrogen laser driven by a fast Blumlein discharge circuit is shown in Fig. 2(b) [1].



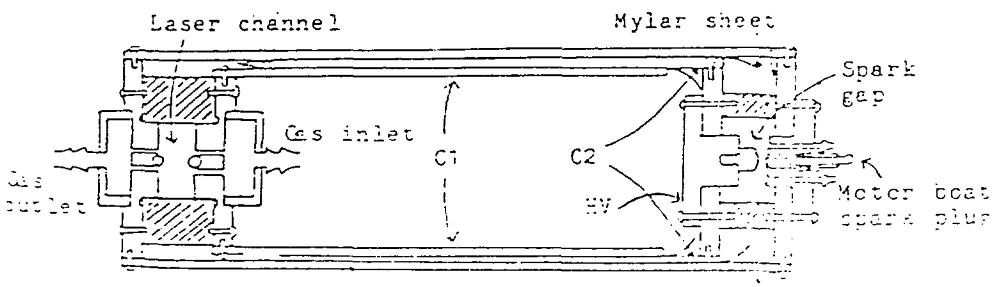


Fig. 2 Schematic diagram of: (a) the circuit diagram and (b) a nitrogen laser [1]

The output of a nitrogen laser is normally a short laser pulse of 5-10 nanosecond (ns) long with peak powers up to a megawatt (MW). The high UV output power of a nitrogen laser makes it a useful laser source for the excitation of fluorescence as well as in pumping liquid dye lasers. Four nitrogen lasers of different sizes and different power specifications have been designed and constructed and are used for different areas of spectroscopy including palm fruit ripeness and palm oil oxidation level analyses [2] and pollution monitoring [1,3].

(2) TEA Carbon Dioxide Lasers

Over the past few years, three different designs of a transverse excitation atmospheric (TEA CO_2 lasers have been designed and constructed with laser output which ranged from 300 m. to 4J [4,5,6]. Fig. 3 shows the schematic of the 4-Joule TEA-CO2 laser system [4] which employs profiled and nickel-plated electrodes. Two rows of small of capacitors are mounted along both sides of the laser channel. During switching of the spark gap, high voltage spark across the gaps between these capacitors which produces UV radiation for preionizing the lasing gas medium. The formation of arcs allow the small capacitors to be charged by the dumping of the storage capacitor which eventually discharge across the laser channel when the laser-channel impedance is lowered sufficiently by the UV-preionisation.

These CO_2 lasers are very efficient, typically more than 10% efficient in converting from electrical to optical energy, have very high energy output. These laser output when focussed will produce the electrical breakdown in air to form sparks. When appropriately masked and focussed, these lasers will produce permanent markings on plastics and form the basis for the industrial marking of IC components [4]. These lasers have also been used for the annealing of amorphous silicon semiconductor materials as a technique for the processing of efficient solar cell fabriation [6].

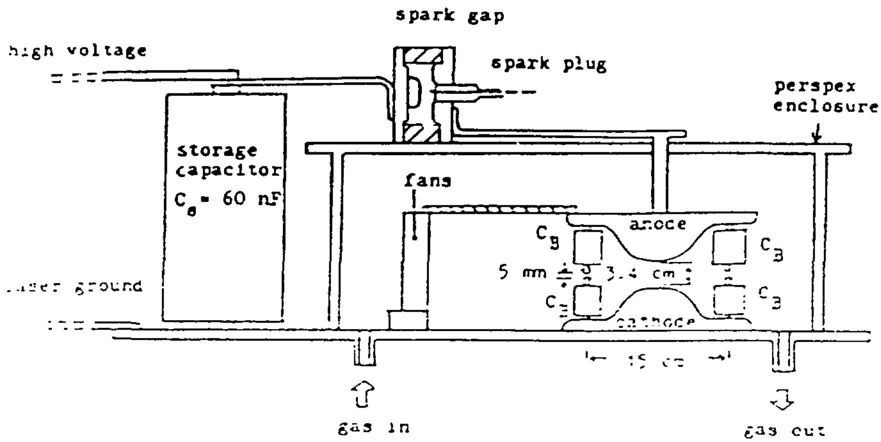


Fig. 3 End-on view of a high power TEA-CO2 laser system [4]

(3) Excimer Laser-XeCl

A class of high-power UV lasers known as the excimer lasers have found important applications in the electronics industry for photolithography in i.c. manufacturing. These rare-gas halide lasers have also found many other applications in science and industries. However, these lasers are technologically more demanding than those of a nitrogen laser and are more expensive to construct.

An excimer laser with xenon and chlorine gases forming the excimer laser medium was recently constructed [7]. The laser delivered about 60 millijoule (mJ) of laser energy in about 10 ns of pulse width with a output power of 6 MW peak. This laser, besides the very high discharge current requirement, also requires the design of an efficient preioniser system to obtain uniform discharge inside the laser cavity. As shown in Fig. 4, two rows of the capacitors are attached along the laser channel. One of them forms the UV-preionizer when high-voltage arcs are produced between the upper and lower capacitors. The other row of capacitors is used as the main damping capacitor for fast laser-channel discharge.

This laser [7] has been used for pumping dual-wavelength dye laser for atmospheric studies. Other applications of the laser are being explored.

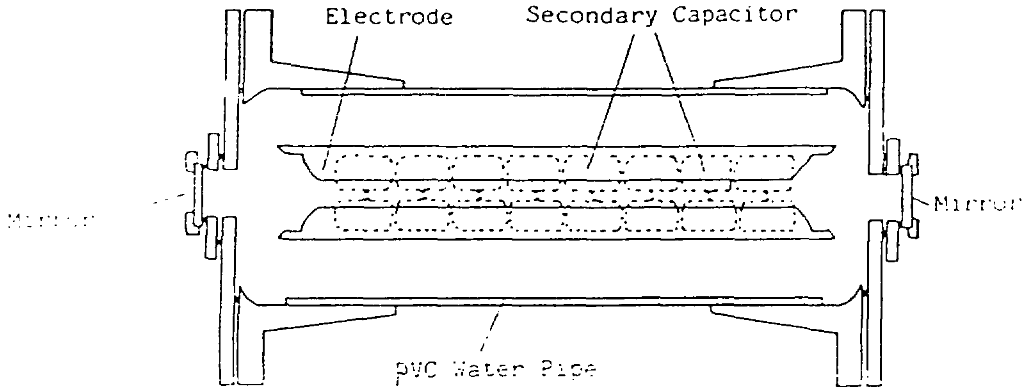


Fig. 4 Sectional view of a XeCl excimer laser [7]

(4) Flashlamp Pumped Dye Lasers

Some flashlamp pumped dye lasers have been designed and constructed. The flashlamps are basically high-voltage discharge tube operating at reduced pressure of air which are then arranged according to geometrical optics as to efficiently excite the liquid dye medium. Fig 5 shows a coaxial flashlamp pumped dye [8] which have been operating with rhodamine dyes as a lasing medium. The yellow output of the laser was designed for potential application in the laser lithotripsy of kidney stone. The power and frequency of the laser is being improved for that purpose.

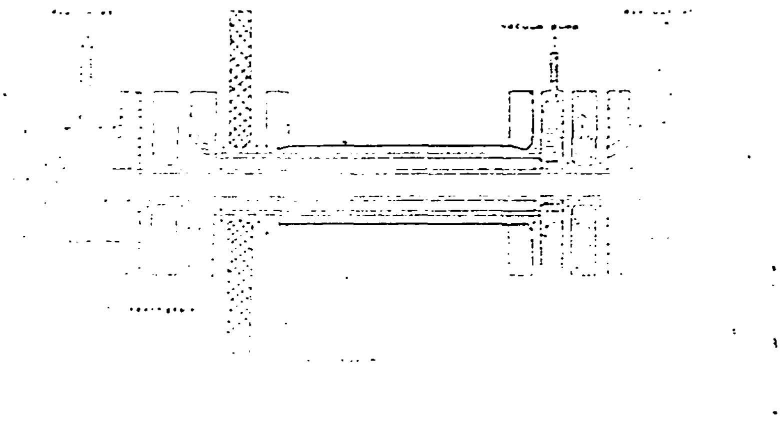


Fig. 5 Sectional view of a coaxial flashlamp pumped dye laser [8]

(5) Metal Vapour Lasers

Since 1989, we have embarked on developing metal vapour lasers. A Copper Bromide [9] and a Gold Metal Vapour [10] lasers started operating after a year of design and construction which included high-voltage resonant charger and high frequency triggering unit for EEV ceramic-sealed hydrogen thyratron. Up to date, the copper bromide laser could only give about 10 watt of output at about 6 kHz of operating frequency and less than 1% of efficiency. This means that an optimization program would be necessary in order to increase its output. This laser is intended for use for laser lithotripsy and other industrial applications.

On the other hand, the gold metal vapour laser gives up to a maximum of 300 mW of output for a short cavity length of 40 cm. It is expected to yield more than 1 W of output at 632.8 nm with a 1 m long cavity tube. Fig. 6 shows the schematic of a coaxial laser system which are common to both designs of the copper bromide and gold metal vapour lasers. The gold vapour laser is intended for use for the cancer therapy program.

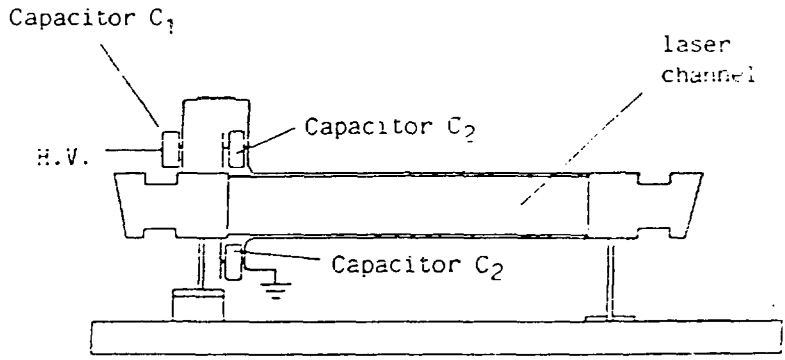


Fig. 6 Schematic diagram for a coaxial metal (copper bromide or gold) vapour laser [9,10]

(6) Solid State Neodymium Doped Glass and YAG Lasers

Nd-YAG and glass lasers have found many applications in industries, science and medicine due to its simplicity in operation and reliability. A high power Nd-glass laser with 4 J output has been designed and developed [11]. Tow compact Nd-YAG lasers [12,13] have also been developed for various laser pulse modulation, Q-switching and modelocking studies. These infrared lasers have also been used for frequency conversion using non-linear optical materials. The miniature (matchbox size) Nd-YAG laser was used for prototype laser range finding studies [12]. Fig. 7 shows a diagram of a compact Nd-YAG laser constructed.

(7) Helium-Nitrogen Laser

This is an extension in the development of nitrogen lasers except two output pulses are obtained simultaneously. This laser requires much higher charging voltage and a two stage Marx generator has been designed. Up to 4 mJ of dual wavelength laser output is obtained for pulse width of about 4 ns. This laser is intended for use in pollution monitoring program. A small matchbox size Nd-YAG was designed in [illegible] laser range finding experiment [14]

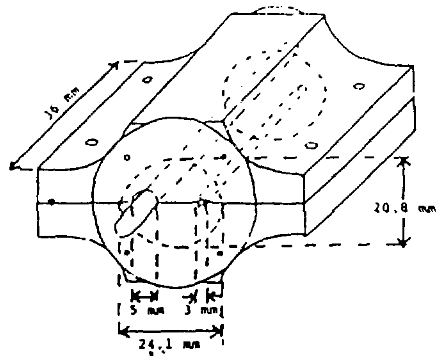


Fig. 7 Schematic diagram of a compact Nd-YAG laser [12]

(8) **Continuous Wave (CW) Carbon Dioxide Lasers**

A prototype high power carbon dioxide laser for material processing of welding, cutting and metal heat treatment purposes have been designed and constructed. This work has been based on an earlier studies of a lower power laser system which has yielded insufficient energy (10 W) for materials processing [15]. The prototype laser is a transverse discharge, transverse gas flow system instead of the longitudinal discharge configuration of the smaller laser system. Various parametric studies have been conducted on the prototype system. Once completed, a scaled up 1 kilowatt laser system suitable for various precision metalurgical applications will be developed.

2.2 DEVELOPMENT OF LASER-BASED APPLICATIONS

1) **Industrial Applications of Lasers**

A prototype high power TEA-Carbon dioxide laser has been developed for the marking of electronics components in 1988 [4]. A sample of a marked plastic i.c. component is shown in Fig. 8. The laser marker system has since been upgraded to be capable of operation at high repetitive operation. Various design features have been improved. For the system to be operational as a laser marker for the electronics industry, a mechanical feeder system has yet to be developed.

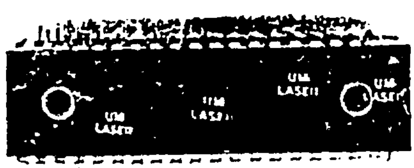


Fig. 8 A sample of a laser marked plastic i.c. component [4]

At the same time, the design and development of a prototype high power CW-CO2 laser for cutting and welding of materials has been carried out. A low power device has been in operation but has too low power for industrial applications. The construction of the high power unit has been completed and the operating characteristics of this laser system has been investigated. A number of design features have been modified and adapted to achieve the necessary threshold lasing conditions. This laser system has been designed for the cutting and welding of materials.

2) **Medical Applications of Lasers**

The group has made significant advances in the field of photodynamic therapy (PDT) of cancer using lasers [16,17,18]. Besides the development of laser devices for cancer therapy, the group has proposed a new protocol of immediate PDT which has been proven to be at least 5 times more effective, in terms of the dosage of the drug needed and the response to treatment obtained, when compared to the conventional protocol currently practised. Fig. 9 shows a comparison of the results obtained using the new protocol as compared to that obtained using the conventionally praticed protocol. Clinical trials using this new procedure of cancer treatment will be conducted using drugs prepared at the Clean Room constructed. A provisional licence to manufacture the drug at the University of Malaya has been obtained.

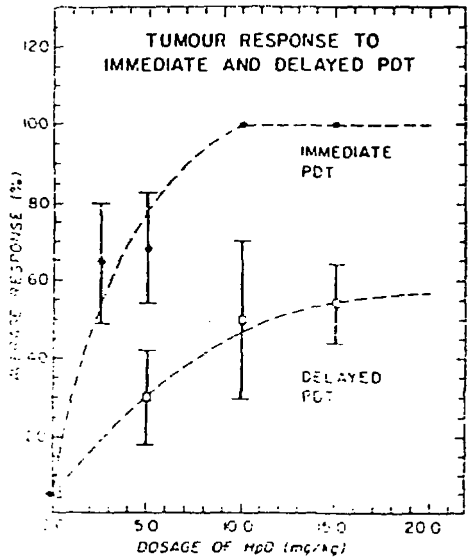


Fig. 9 A comparison of the tumour response to the immediate PDT and the delayed PDT [18]

The group is also involved in the development of various laser systems for medical applications. A more efficient metal vapour laser system [10] has been successfully developed for cancer treatment. A patent [19] on a laser light delivery system for cancer treatment has also being submitted by members of the group.

3) **Agricultural Applications of Lasers**

Using a nitrogen laser constructed, a microcomputer controlled laser induced fluoresc[illegible] system has been developed for the processing of palm fruit ripeness [2] as well as for palm oil oxidation level detection [20]. Since most organic materials fluoresces strongly under high power UV laser light, such laser induced fluorescence technique has been developed to provide a remote sensing method of extracting information on palm fruit ripeness and palm oil oxidation level arising from shipping and storage. Fig. 10 shows a schematic arrangement of a laser induced fluorescence system and some results obtained for palm oil related studies.

Since a large amount of data will have to be gathered for routine and rapid processing purposes, it is needed that faster data acquisition procedures be developed. An optical multichannel analyser system for rapid data acquisition and processing has been developed.

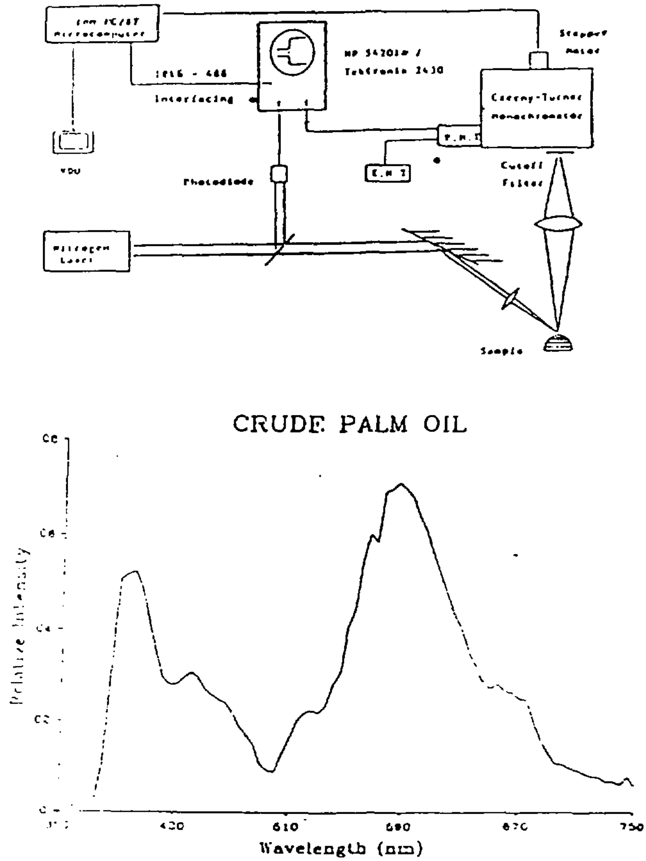


Fig. 10(a) Experimental set-up for laser induced fluorescence of palm oil using nitrogen laser.
(b) A characteristic fluorescence spectra of crude palm oil. [2,20]

4) **Pollution Studies Using Lasers**

Light Detection and Ranging (LIDAR) techniques have been developed for the detection of trace pollutant concentrations in the atmosphere to less than 10 parts-per-billion (ppb) [1,7]. This is based on the technique of simultaneous dual wavelength from single dye laser which has been developed for monitoring of ambient NO2 concentration to less than 10 ppb (parts-per-billion) [1]. A new type of much higher power laser, a UV excimer laser, has also been developed to enable higher power operation of the lidar system as well as for detection of SO2 and ozone [7].

Other optical and laser techniques for the measurement of atmospheric pollution have also been developed. These included optical differential absorption spectrophotometer [21] based on halogen lamps as light source as well as using Mie scattering methods for the measurement of atmospheric visibility accurately.

Fig. 11 shows a schematic of the experimental setup of a simultaneous dual channel spectrophotometric detection system for ground based monitoring of atmospheric pollutants.

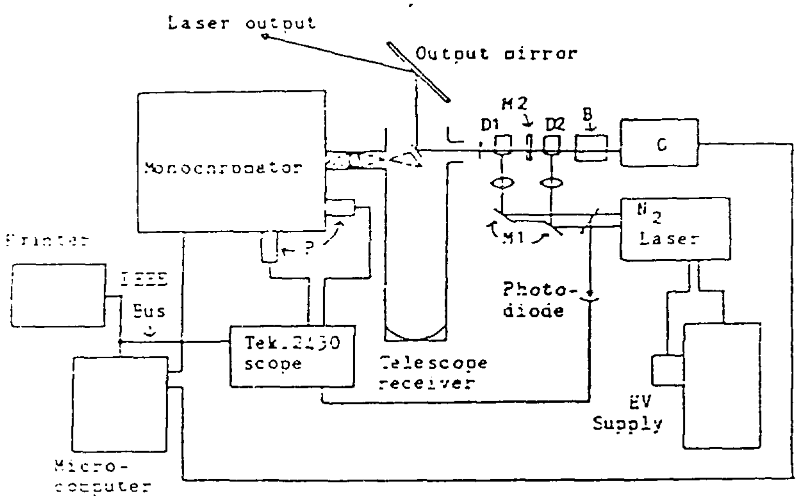


Fig. 11 Schematic diagram of dual wavelength laser lidar system [1,7]

5) **Lasers for Non-Destructive Testing of Materials**

Work has been conducted for the NDT speckle interferometric studies of materials [22]. Non-destructive tesing of materials such as rubber tyres and metal fatiques due to either mechanical or thermal stresses can be performed rapidly and reliably using laser interferometric techniques. Such interferometric methods have been conducted using digital imaging for rapid data acquisition and processing. Applications to industrial processes and monitoring are being conducted.

Work has also been conducted on the investigations of crystal damages due to light irradiation [23].

4 SUMMARY OF PROGRESS ACHIEVED

Over the period 1988 to 1990, the group has achieved significant progress in the development of lasers and in the applications of these laser systems in diverse areas of interest. The group had developed many types of lasers [24] for various applications, ranging from industrial, medical, agricultural, environmental monitoring, materials processing etc. Some of the lasers are near marketable status. The group had also made significant contribution in the field of cancer treatment using lasers by proposing a more effective photodynamic treatment procedure which has shown better tumour response to treatment than previously obtained. Clinical trials will begin in [illegible]

The laboratory is now a recognised center of excellence in the field of lasers and electro-optics. Four training programs (3 weeks each, in 1984, 1986, 1988 and one 1990) on lasers and electrooptics research were conducted by the group for physicists from the developing countries as well as from

Malaysia, funded by UNESCO and other international agencies. The laboratory has also conducted a 6-month training program for the United Nations University for physicists from the developing countries in the field of laser research in 1986.

PERSPECTIVE

While some progress has been made in laser research at the University of Malaya, it is noted that the emphasis in the first ten years have been biased towards the development of different types of laser systems as technological development. However, in the last few years, with the availability of more advanced instrumentations, various studies of a more detailed nature have been initiated. Thus, time resolved spectroscopy of laser initiated sparks in different materials as well as basic ionisation processes in gas discharges are being initiated. In parallel with these are the further development of applications of lasers in various areas of medicine, agriculture and industrial applications.

As an important by-product of this program, the research group has been actively involved in the training of higher degree candidates and technical manpower. A list of the Ph.D. and M.Phil. graduates is shown in Table 2. These graduates are now contributing actively in the further development of these laser and electro-optic technology either in other local institution of higher learning or in local research institutions or in the private industrial sector. The research program continues to support the training of other higher degree candidates. A list of the current research projects undertaken is shown in Table 3.

Table 2 List of higher degrees (Ph.D. and M.Phil.) completed between 1988-1990

Ph.D. Dissertation	Theses Titles and Supervisors
1. M. Olivo *(1990)*	*Photodynamic Cancer Therapy: Development of a simple light source and investigation of an alternative treatment procedure'.* (Supervisors: K.S. Low, B.C. Tan and L.M. Looi)
M.Phil. Theses	**Theses Titles and Supervisors**
1. C.K. Lee *(1988)*	*'Differential optical absorption spectrometry for measurement of atmospheric pollution'.* (Supervisors: K.S. Low, B.C. Tan and L.M. Looi)
2. S.J. Tan *(1988)*	*'Investigation of a high power TEA-CO2 laser for marking purposes'.* (Supervisors: K.S. Low, B.C. Tan and Y.H. Chen)
3. S.C. Tan *(1989)*	*'Fabrication and characterization of a coaxial dye laser for the study of the photothermal effect'.* (Supervisors: B.C. Tan, C.S. Wong and K.S. Low)
4. K.H. Wong *(1989)*	*'Laser induced fluorescence studies of organic materials'.* (Supervisors: K.S. Low, B.C. Tan and Y.H. Chen)
5. M.J. Zainuddin *(1989)*	*'Investigation of 99mTechnetium-labelled haematoporphyrin derivatives for nuclear imaging of malignancies'.* (Supervisors: M. [illegible]asothy, K.S. Low and N.H. Tan)
6. O.C. Chee *(1989)*	*'Investigation of a compact Nd-YAG laser for light detection and ranging'* (Supervisors: K.S. Low, H. Ahmad and B.C. Tan)

Table 3 List of current higher degrees programs (1991)

Ph.D. Programs	Project Titles and Supervisors
1. C.K. Ang	*Speckle Interferometry for Non-Destructive Testings of Materials.* (Supervised by B.C. Tan and Y.H. Chen)
2. K.H. Wong	*Wong Kah Hieng - Time resolved spectroscopy of complex ionisation products produced by high power lasers.* (Supervised by K.S. Low and B.C. Tan)
3. Y.A. Tan	*Laser spectroscopy of palm oil related materials.* (Supervised by K.S. Low)
M.Phil Programs	**Project Titles and Supervisors**
1. K.H. Chong	*Dual wavelength He-N2 lasers for pollution monitoring.* (Supervised by K.S. Low and B.C. Tan)
2. K.H. Cheah	*Gold vapour lasers for cancer therapy.* (Supervised by K.S. Low and B.C. Tan)
3. M.L. Liew	*Copper bromide lasers for medical applications.* (Supervised by K.S. Low and B.C. Tan)
4. K.C. Tee	*Two phase fluid flow studies using lasers.* (Supervised C.F. Than and K.S. Low)
5. W.S. Seow	*X-ray productions using high power lasers.* (Supervised K.S. Low and T.Y. Tou)
6. K.F. Lee	*Non linear optical studies using solid state lasers.* (Supervised by H. Ahmad and K.S. Low)

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It is noted that this multi-disciplinary research programs involves many areas of applications in different disciplines. Specialist input from researchers from the Faculty of Medicine and Engineering have been included in some of these research projects on a project basis. Their active collaborations and contributions are acknowledged.

REFERENCES

[1] Tan, C.H. and Low, K.S., Proc. 3rd Tropical College on Applied Phys., Kuala Lumpur, 1988, p524-531.

[2] Wong, K.H., *'Laser induced fluorescence studies of organic materials'*, M.Phil. Thesis, University of Malaya, 1988.

[3] Tan, C.H., *'A differential absorption lidar system based on a tunable dye laser'*, Ph.D. Thesis, University of Malaya, 1988.

[4] Tan, S.J. and Low, K.S., J. Fiz. Mal. 9, 15 (1988).
Also, Tan, S.J., *'Investigation of a high power TEA-CO_2 laser for marking purposes'*, M.Phil. Thesis, University of Malaya, 1988.

[5] Ang, C.K., Tan, S.J. and Low, K.S., Proc. 3rd Tropical College on Applied Phys., Kuala Lumpur, 1988, p448-454.
Also, Ang, C.K., *'Investigation of uv-preionised atmospheric pressure gas laser'*, M.Sc. Thesis, University of Malaya, 1988.

[6] Poh, L.K., Chen, Y.H., Tan, B.C., *'Propagation of melt front in an amorphous silicon film irradiated by a dye laser'*, Nat. Physics Symp., June, 1989, IFM publication, p218.
Also, Poh, L.K., Ph.D. Thesis, University of Malaya, 1990.

[7] Lau, S.L. and Low, K.S., Proc. National Phys. Symp., Kuala Lumpur, 1989.
Also, Lau, S.L., *'Studies of atmospheric pollution propagation and dispersion'*, Ph.D. Thesis, University of Malaya (submitted, 1991).

[8] Rasiah, I. and Tan, B.C., Proc. 4th Tropical College on Applied Physics, 1990 (to be published).

[9] Liew, M.L., M.Phil. Thesis (in preparation), University of Malaya.

[10] Cheah, K.E., M.Phil. Thesis (in preparation), University of Malaya.

[11] Ahmad, H., *'Optical Amplifier'*, Nat. Physics Symp., 1989, IFM Publication, p199.

[12] Chee, O.C. and Low, K.S., Proc. 3rd Tropical College on Applied Phys., Kuala Lumpur, 1988, p442-447.
Also, Chee, O.C., *'Investigation of a compact Nd-YAG laser for light detection and ranging'*, M.Phil. Thesis, University, Malaya, 1989

[13] Ahmad, H., *'Nd-glass laser'* (unpublished).

[14] Chong, K.H., M.Phil. Thesis (in preparation), University of Malaya

[15] Poh, L.K. and Chen, Y.H., Proc. 2nd Tropical College on Applied Phys. Kuala Lumpur, p353-366.

[16] Low, K.S. and Olivo, M., Invited Lecture on *'Review of recent progress of photodynamic therapy of cancer'*, Proc. International Workshop on Lasers and Applications, Indore, India, November, 1990 (to be published by Wiley-Eastern Publ. Co.).

[17] Zainuddin, J., Olivo, M., Baskaran, G., Paramsothy, M. and Low, K.S., *'Efficacy of 99m-Tc-labelled Hpd for imaging and therapy of neoplastic tissues'*, Abst. World Congress on Medical Physics, San Antonio, November, 1989.
Also, Zainuddin, J., *'Investigation of 99m Technetium-labelled haematoporphyrin derivatives for nuclear imaging of malignancies'*, M.Phil. Thesis, University of Malaya, 1989.

[18] Olivo, M., Low, K.S., Looi, L.M. and Tan, B.C., *'Investigation of immediate photodynamic therapy for cancer treatment'*, Med. Sci. Res., 1989, 17, 31.
Also, Olivo, M., *'Photodynamic cancer therapy: development of a simple light source and investigation of an alternative treatment procedure'*, Ph.D. Thesis, University of Malaya, 1990.

[19] Low, K.S. and Tan, B.C., *'A laser device for cancer treatment'* (patent submitted, 1989.

[20] Yeoh, K.H., *'Laser induced fluorescence studies of palm oil oxidation level'*, M.Sc. Thesis, University of Malaya (under preparation).

[21] Lee, C.K., *'Differential optical absorption spectrometry for measurement of atmospheric pollution'*, M.Phil. Thesis, University of Malaya, 1988.

[22] Ganesan, A.R., Ang, C.K., Sirohi, R.S. and Tan, B.C., *'Low light illumination digital speckle pattern interferometry'*, 4th Asia Pacific Physics Conf., Seoul, August, 1990.

[23] Santhiran, N., Radhakrishna, S. and Tan, B.C., *'Laser radiation damage in cesium bromide crystals'*, 4th Asia Pacific Physics Conf., Seoul, August, 1990.

[24] Low, K.S. and Tou, T.Y., Invited Lecture on *'Development of lasers and applicationsat the University of Malaya'*, Proc. International Workshop on Lasers and Applications, Indore, India, November, 1990 (to be published by Wiley-Eastern Publ. Co.).