Development of a red diode laser system for Photodynamic Therapy

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ABSTRACT

The effectiveness of Photodynamic treatment modality has been proven experimentally for a large variety of tumours, during the last years. This therapy utilizes the combined action of light and photosensitising drug. Until now, a disadvantage of PDT has be the low tissue penetration of light, at the wavelengths of most commonly available lasers, for clinical studies.
The red wavelength offers the advantage of increased penetration depth in tissue, in addition several new photosensitizers present absorption band at the region 630nm to 690nm. The development of high power red diode laser system for photodynamic therapy, has provided a cost effective alternative to existing lasers for use in PDT.
This paper will describe the system design, development and performance of a diode laser system, connected with a fiber optic facility, to be used for PDT. The system was based on a high power (100mW output power) semiconductor diode laser emmitting at 655nm. The laser output power was approximately 60mW at the output of a 62.5/125/900 micron fiber optic probe.
Full technical details and optical performance characteristics of the system will be discussed in this paper.

1. REQUIREMENTS

The PDT treatment depends on the action of light of particular wavelength and optical power so to activate a photosensitising drug preinjected in tissues. Therefore a laser system for PDT should operate at specified wavelength with maximum available power and a suitable fiber optic beam delivery system to allow penetration to internal organ treatment. Capability of optical power and wavelength tuning is an appreciated extra advantage. To ensure safety of laser diode operation a stable current source should be used. A cooling system is neccessary to keep temperature stability. A fiber optic delivery system allows for flexible handling as indicated in Figure 1.

2. LDS660/100-SMA SYSTEM DESIGN

The LDS660/100-SMA system developed is based on the only currently commercially available red laser diode emmitting 100mW at 659nm@20^{o}C (typical 655 nm specified by manufacturer). The laser diode model is CQL822/D made by PHILIPS Optoelectronics Center and constructed of InGaP/InGaAlP semiconductor junction. It is a double channel device packaged in a typical 9mm casing. Operating temperature -10/+30^{o}C and low threshold current 130mA are specified. The operating current is 250mA and operating voltage is 2.6-3V. The emmitting cone of the chip is elliptically divergent. The farfield angle parallel to junction is 8 degrees while the perpendicular to junction is 35 degrees. To focus effectively the light emmitted from the chip a first step collimation (NA 0.25) and second step focusing (NA 0.275) lens system is used with antireflection coating at 660nm to match the output of the diode. The patented manufacturing of the optical systems allows for three degrees of freedome so to focus the light.
Due to the double channel construction a special type of double focus lens should be used. Instead an inclined off axis alignment technique was developed to couple and combine sufficient light from both emmitting areas of the semiconductor. The lens match the NA of the optical fiber that is connected via a suitable female fiber adaptor. The focal point is prealigned to be on the core of the fiber.

3. FIBER DELIVERY

The beam delivery system is a combination of two pieces of optical fiber. The internal piece allows for the permanent alignment of the laser diode output to a 62.5/125/900 micron fiber using an SMA type connector for mating. This is a short length of only 0.5m. The external piece is a detachable fiber 62.5/125/900 micron of NA 0.275 or alternatively a 200/230/900 micron. This option allows the user to alter the optical power and geometrical area suitable for treatment. The far end of the fibers have been polished so to reduce light scattering and attenuation and emit a circular homogenious distribution of light. The optical fiber is heat cured epoxy glued in a glass cappilary of 1.5 mm external diameter. Both fiber and capilary have been polished to a fine lapping of 1 micron grade to achive maximum flatness. This technique prevents the fiber end from braking and possible damage when used in combination with endoscopes for internal treatment.

4. COOLING-DRIVING

The most important feature for the safe operation and long lifetime of the laser is cooling. The laser chip operates at 15^{o}C to ensure stable outpout and to prevent thermal damage. It is generally desirable to operate the laser at as stable and low a temperature as possible. An aluminum mounting plate of the laser is used for passive heat sink. Two thermoelectric coolers (TEC) modules (model CP0.8-31-0.6L Melcor Qmax= 4.4W) are cooling the laser diode and part of the aluminum. The TEC modules are placed symmetrically to the laser diode for better thermal stability as shown in Figure 2.

The laser diode casing acts as anode therefore touch with metal parts may cause damage. To prevent that the aluminum sheet is connected to the laser diode mount using only plastic bolts.

The semiconductor TEC module is designed based on Peltier effect to absorb heat produced by the laser diode at the cold junction and transfer it to the hot junction at a rate proportional to the current passing throught the thermocouple. The heat at the hot junction is then dumped into a large area aluminum heat shink that is air cooled. Driving the TEC modules is as important as driving the laser itself. Using a temperature controller driver can maintain temperature stability to within 0.005^{o}C[1]. This is a very important factor to set thermal equilibrium and to control laser temperature for limited wavelength tuning. Special care is taken for the low noise caused in cabling connections. Therefore D9 type connectors are used.

The temperature controller unit model LDT5525 made by ILX Lightwave is used. A manufacturer supplied calibrated thermistor allows for precise temperature measurement. At Ilimit =1A and Tlimit=38^{o}C a preset temperature of 15^{o}C is set for cooling the laser.

Due to the requirement for stable current driving of the laser diode a precision current source model LDX-3525 made by ILX Lightwave is used to avoid instability and transient current spikes caused by most laboratory DC supplies. Ilimit=250mW and this maximum value set by the operator can by no means exceeded to ensure the laser safety..

5. PERFORMANCE

Using an optical power meter model 13PDC001/IEEE made by Melles Griot equipped with special fiber adaptor the outpout power of the system is measured versus the driving current. A comparison is performed between the outpout power of the system and the outpou power at the end face of the 3 m long 62.5/125/900 micron optical fiber to evaluate the actual optical power emmitted on tissue during treatment. Max values of 63mW towards 57mW indicate a difference of 6mW or 0.43dB lost on the SMA connection and the attenuation of the fiber as indicated in Figure 3. According to values measured for CW operation at 15^{o}C the total efficiency of the laser diode system at the end of the fiber is 57%, that is a very good value considering the attenuation caused by the lens system, the two connections and the two optical fibers included.

Using an Optical Spectrum Analyser model.... made by ..... the wavelength shift is determined according to the temperature of the laser diode casing. A total shift of 3 nm is measured for 10^{o}C temperature difference or 0.3nm/^{o}C as shows Figure 4. Considering the operating temperature rangeof the laser a tuning in outpout is possible starting from 652.5 nm at 0^{o}C to 660 nm at 25^{o}C or 7.5 nm range to cover the middle area of the exitation wavelength for available drugs between 630 and 690 nm[2].

6. REFERENCES

1. L.A.Johnson, "Controling temperatures of diode lasers and detectors thermoelectrically", ILX Lightwave application not, April 1988
2. C.G.Dupuy et al, "High power red diode laser system for Photodynamic Therapy", SPIE Biomedical Optics '94, #2131-47

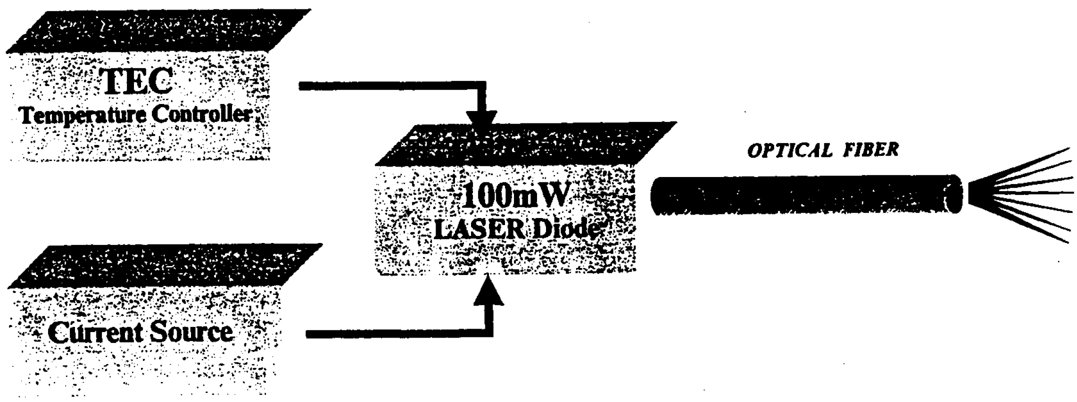

Fig. 1. System design and main parts

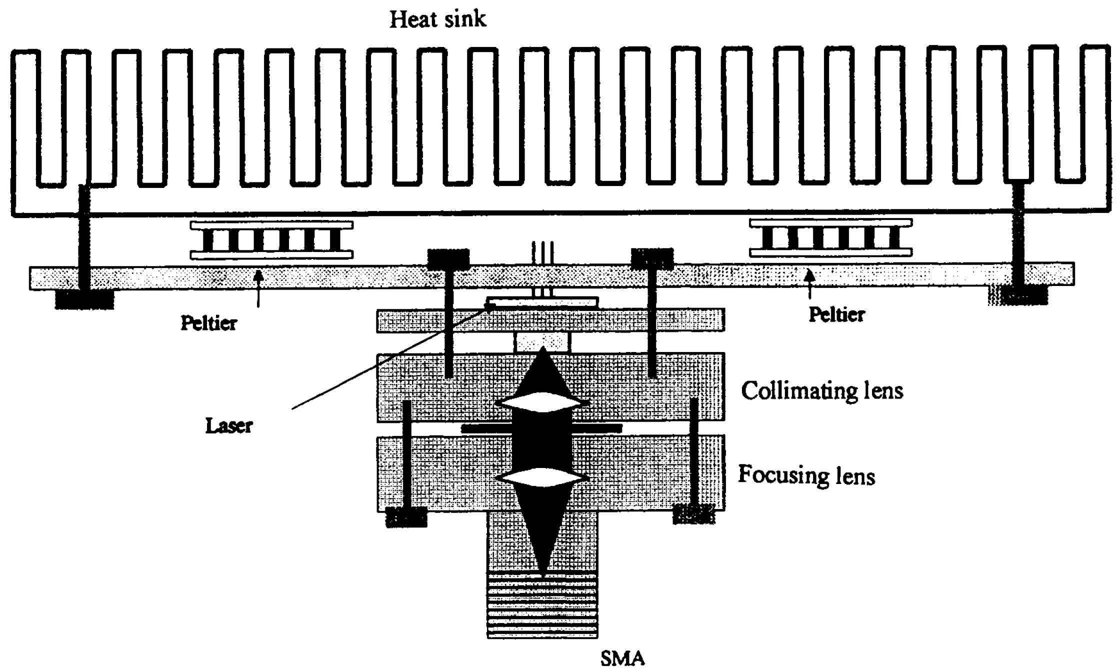

Fig. 2. Drawing of the lenses and TEC modules used in LDS660/100-SMA

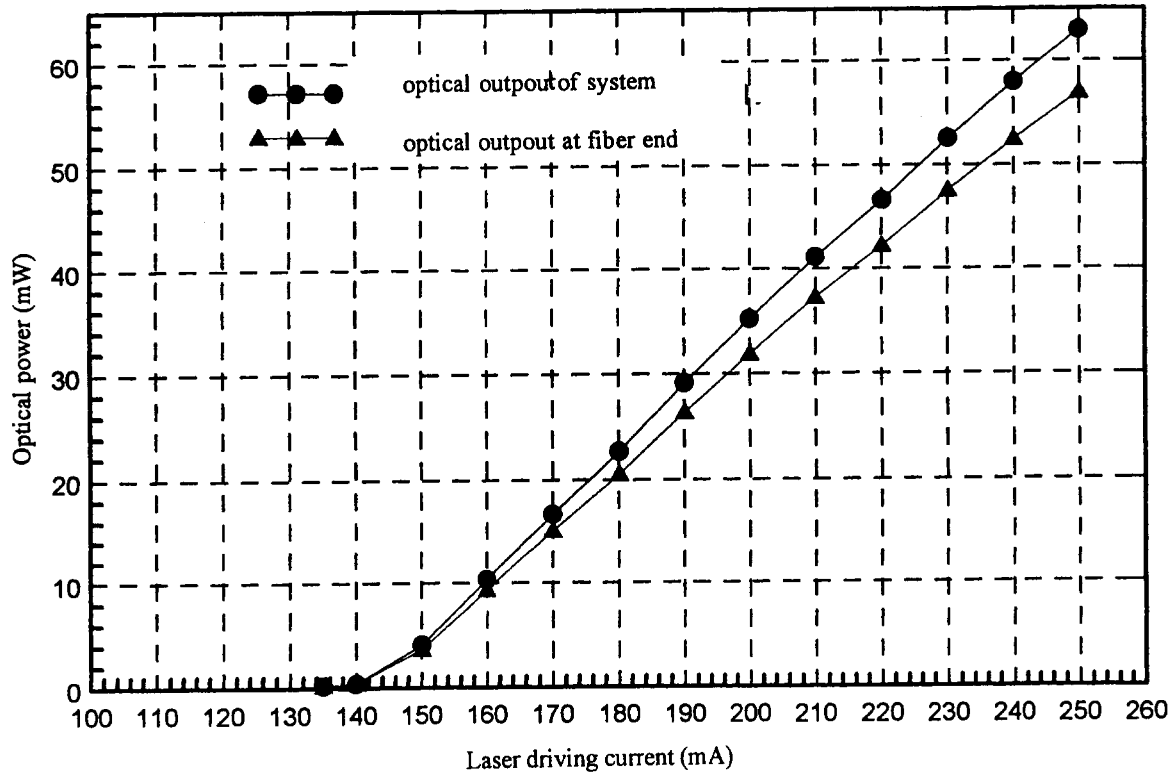

Fig. 3. Outpout power versus drive current at the outpout of the system compared to same graph at the end of the optical fiber.

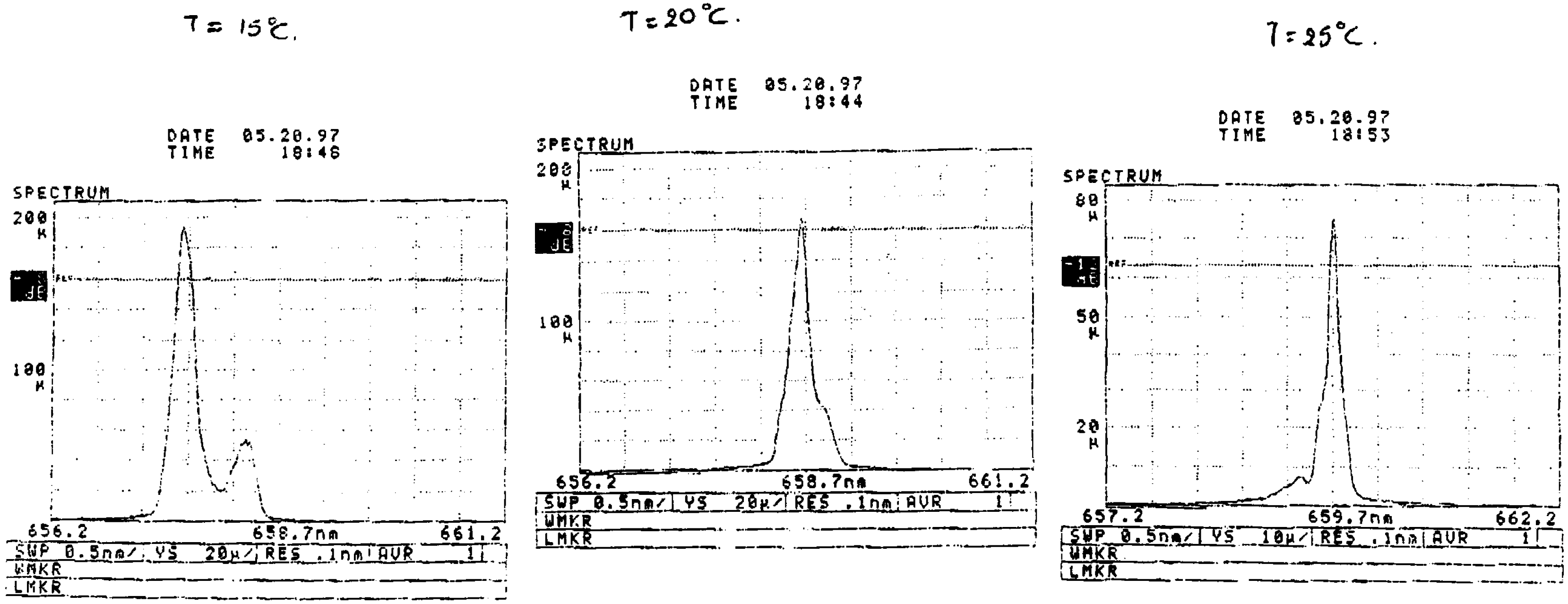

Fig. 4. Wavelength outpout versus temperature of the laser.