CLEO 87

centers is actually increasing with decreasing gas pressure. However, a reduction of the gas pressure gives larger variations in the gain spectrum which require a tuning arrangement with increased frequency selectivity. **(12 min)**

1. B. K. Deka, M. A. Rob, and J. R. Izatt, Opt. Commun. **57**, 111 (1986).
2. S. Løvold and G. Wang, IEEE J. Quantum Electron. **QE-20**, 182 (1984).
3. S. Landrø and G. Wang, in *Technical Digest, Conference on Lasers and Electro-Optics* (Optical Society of America, Washington, DC, 1984), paper THL1.

Friday **AFTERNOON**
1 May 1987 **FP**
ROOM 307

3:00 PM **Infrared Solid-State Lasers: 2**

John Eggleston, Spectra Technology, Inc., Presider

FP1 Innovative schemes for diffraction-limited lasers

S. DE SILVESTRI, P. LAPORTA, V. MAGNI, O. SVELTO, Centro Elettronica Quantistica e Strumentazione Elettronica C.N.R., Istituto di Fisica del Politecnico, Piazza Leonardo da Vinci 32, 20133 Milano, Italy.

High-power diffraction-limited lasers are of paramount importance for all uses requiring laser beams of high brightness. To achieve the highest brightness, the fundamental mode must fill the laser medium to the greatest extent. To this end, we consider in this work three different resonator schemes, applicable to cw or pulsed laser sources, which can improve the performances of stable as well as unstable resonators.

Let us first consider stable resonators. The first scheme proposed is strictly related to the recently developed phased-array semiconductor lasers.[1] Our proposal concerns the design of a bidimensional plane mask containing suitably located holes to be inserted into the laser resonator near one mirror. The mask should generate a bidimensional beam array, which, in appropriate conditions for the hole locations, is phase-locked by diffraction (bidimensional phased array laser). This system introduces a new concept in phased arrays for any kind of laser, and it sheds new light on the behavior of semiconductor phased-array lasers and of the recently developed two- and three-phased-channels CO_2 waveguide lasers.[2] Preliminary experiments performed on a pulsed Nd:YAG laser have demonstrated the feasibility of this proposal. The simplest mask considered was that containing two holes of appropriate diameter so that a nearly TEM_{00} mode was passing through each of them. Depending on the distance between the two holes, the two beams have been observed to be (1) unlocked at a large distance; (2) locked in opposite phase (TEM_{01} mode) at a suitably small distance; and (3) locked in phase at an intermediate distance. The achievement of the previous locking conditions is apparent by considering the far-field intensity distribution of the beam. The conditions of phase locking have also been achieved for three holes located along a straight line and for holes located along a square pattern.

The second scheme, which still concerns stable resonators, relies on the optimization procedure of cw or high-repetition-rate solid-state lasers with a thermal lens effect. The large-mode volume inside the laser rod can be achieved by choosing the rod position in the resonator and mirror curvatures according to simple design equations, which take into account the dynamic and mechanical stability of the resonator.[3] The extension of this analysis to resonators with an internal optical system is discussed.

For unstable resonators, the use of mirrors with a tapered reflectivity profile has been recognized for many years as an efficient means of generating a large fundamental transverse mode with a fairly uniform spatial profile. So far, however, very few devices with quasi-Gaussian reflectivity profiles have been experimentally demonstrated. We recently proposed and studied a radially variable Fabry-Perot interferometer (named RAVI) as a tapered output coupler.[4] In this work we consider two novel implementations of quasi-Gaussian output couplers, which make this device practicable and applicable to industrial systems based on a radially variable interferometer and a new thin-film deposition technique using a focused CO_2 laser as the heating source.

We believe that the results represent an important step toward the ultimate performances of large-aperture diffraction-limited lasers.
(Invited paper, 25 min)

1. D. R. Scifres, W. Streifer, and R. D. Burnham, IEEE J. Quantum Electron. **QE-15**, 917 (1979).
2. L. A. Newman, R. A. Hart, J. T. Kennedy, and A. J. DeMaria, in *Technical Digest, Conference on Lasers and Electro-Optics* (Optical Society of America, Washington, DC, 1986), paper WF1.
3. V. Magni, Appl. Opt. **25**, 107 (1986).
4. S. De Silvestri, P. Laporta, V. Magni, and O. Svelto, Opt. Lett. **12**, 84 (1987).

FP2 Simple method for electronic feedback stabilization of an actively mode-locked and *Q*-switched Nd:YLF laser

R. P. JOHNSON, N. K. MONCUR, L. D. SIEBERT, KMS Fusion, Inc., 3621 South State Rd., Ann Arbor, MI 48106.

The actively mode-locked and *Q*-switched Nd^+ oscillator first proposed and analyzed by Siegman and Kuizenga[1] has been widely used in recent years for the generation of high-power short pulses for laser fusion research. These oscillators generally use acoustooptic modulators for both mode locking and *Q*-switching. During typical operation the laser is allowed to operate in a quasi-cw mode near threshold for several milliseconds by providing enough loss in the acoustooptic *Q*-switch to offset the gain buildup in the laser rod during pumping. This allows the mode locking to come to a near steady state and relaxation oscillations to dampen before the system is *Q*-switched. The rf signal to the *Q*-switch is then turned off allowing high gain in the oscillator with a resulting *Q*-switch pulse.

These oscillators have been shown to have excellent stability[2] provided they are well isolated from outside optical or electrical disturbances. We have found, however, that in the presence of extremely small perturbing signals relaxation oscillations can recur anywhere in the quasi-cw prelase period. This in turn can cause instantaneous gain fluctuations at the time of the *Q*-switch resulting in pulse-to-pulse variation in buildup time and amplitude of the *Q*-switch pulse. The method described here virtually eliminates these relaxation oscillations and correspondingly stabilizes the oscillator.

A diagram of the laser oscillator is shown in Fig. 1. A photodiode signal is used as feedback to modulate the rf drive to the acoustooptic *Q*-sw[illegible] Stabilization of laser oscillators using feedback [illegible] not new.[3] However, most previous attempts have used electrooptic modulators in the oscillator which require costly high-voltage amplifiers [illegible] supply the feedback signals. On the other hand, modulation of the rf drive to an acoustooptic modulator only requires a typical off-the-shelf low-voltage amplifier and a solid-state AM modulator such as a double-balanced rf mixer.

Results using this technique can be seen by comparing Figs. 2 and 3. Figure 2 shows a typical trace of the oscillator signal during the quasi-cw prelase period. (Bandwidth of the photodiode–oscilloscope combination is 20 MHz. Thus the trace is actually the envelope of the high-frequency mode-locked train.) Characteristic relaxation oscillations in Fig. 2 dampen considerably during the prelase time but are not as reproducible as desired. Figure 3, on the other hand, shows the oscillator in identical conditions except that the feedback system is being used. Only a small remnant of the initial relaxation spike is present followed by a well-controlled quasi-cw lasing period resulting in extremely stable *Q*-switched operation.

Further work is being done to investigate possible improvements in the system. Initial results also indicate that this method is equally applicable to single-mode operation as well as the mode-locked case. **(12 min)**

1. A. E. Siegman and D. J. Kuizenga, Optoelectronics **6**, 44 (1974).
2. D. J. Kuizenga, Opt. Commun. **22**, 156 (1977).
3. E. Panarella and L. L. T. Bradley, IEEE J. Quantum Electron. **QE-11**, 181 (1975).

269

FP3 Single-polarization operation of a Nd^{3+}-doped single-mode fiber laser

J. T. LIN, L. REEKIE, L. LI, U. Southampton, Electronics Department, Optical Fibre Group, Southampton, S09 5NH, U.K.

As a laser source, single-polarization fiber lasers are of considerable interest for many potential sensor applications. The fiber lasers reported to date[1-4] have had essentially unpolarized outputs due to the difficulty of including intracavity polarization control components such as Brewster windows in the compact cavity of the fiber laser. Using a recently developed technique,[5] we incorporated a low-loss high-extinction-ratio single-mode fiber polarizer into the cavity of a Nd^{3+}-doped fiber laser. This technique exploits the interaction of the evanescent field of the lasing mode with a short length of metal embedded in the cladding of the fiber.

An exposed-field *D*-section fiber was fabricated by polishing a Nd^{3+}-doped fiber preform to within a short distance of the core and then sleeving. This was then pulled into a single-mode fiber having a distance between the core and exposed surface of ~4 μm (Fig. 1). The fiber exhibited birefringence due to the induced-core ellipticity and thermal stress. The laser cavity was formed by cleaving the fiber and butting to a 35% reflectivity output mirror M_2 with an intracavity microscope objective (20X, 0.4 N.A.) at the launch end (Fig. 2). The input mirror M_1 had a transmission at the pump wavelength of 85 and >99% reflectivity at the lasing wavelength of 1.09 μm. An Ar^+-ion laser operating at 514.5 nm was used as the pump source. The output from the fiber laser was filtered and passed through a polarizer having an extinction ratio of 50 dB. With no metal inserted into the *D* section of the cladding, the laser was found to oscillate on the two orthogonal eigenmodes of the cavity, each with different lasing threshold and slope efficiency. A 2-mm length of gallium was then injected into the *D* section, and this formed the basis of the fiber polarizer. This created a strong differential mode attenuation which forced the laser to oscillate in a single polarization. The lasing characteristic is shown in Fig. 3. The high lasing threshold is due to the insertion loss of the microscope objective in the cavity. Using this technique, an extinction ratio of 3500:1 between the orthogonal polarization modes has been measured for an output power of 20 mW at 1.09 μm. Due to the low insertion loss of the polarizing element (typically 0.1 dB), semiconductor diode laser pumping of this device is also possible. This, together with single-polarization operation of a Er^{3+}-doped single-mode fiber laser operating at 1.55 μm, is reported. **(12 min)**

1. R. J. Mears, L. Reekie, S. B. Poole, and D. N. Payne, "Neodymium-Doped Silica Single-Mode Fibre Lasers," Electron. Lett. **21,** 738 (1985).
2. R. J. Mears, L. Reekie, S. B. Poole, and D. N. Payne, "A Low Threshold Tunable and CW and *Q*-switched Fibre Laser Operating at 1.55 μm," Electron. Lett. **22,** 159 (1986).
3. I. M. Jauncey, J. T. Lin, L. Reekie, and R. J. Mears, "Efficient Diode-Pumped CW and *Q*-switched Single-Mode Fibre Laser," Electron. Lett. **22,** 198 (1986).
4. L. Reekie, R. J. Mears, D. N. Payne, and S. B. Poole, "Tunable Single-Mode Fiber Lasers," IEEE/OSA J. Lightwave Technol. **LT-4,** 956 (1986).
5. L. Li, G. Wylangowski, D. N. Payne, and R. D. Birch, "Broadband Metal/Glass Single-Mode Fibre Polarisers," Electron. Lett. **22,** 1020 (1986).

FP4 Operation of Ho:YAG at intermediate temperatures

NORMAN P. BARNES, NASA Langley Research Center, Hampton, VA 23665; DONALD J. GETTEMY, Los Alamos National Laboratory, Los Alamos, NM 87545.

While Ho:YAG has proved an efficient laser, operation has been limited in most cases to cryogenic temperatures. To avoid the problems associated with cryogenic cooling, laser operation at temperatures intermediate to cryogenic temperatures and room temperature is explored. Both the measurement of basic parameters and the engineering aspects are presented.

Total efficiency of the multiply doped Ho:YAG laser can be optimized by selecting the optimum operating temperature for the laser. Cryogenic temperatures are often employed with this laser material to depopulate the lower laser level, which has a relatively high thermal population at room temperature.[1,2] At these temperatures, efficient operation has been achieved for both continuous and pulsed operation. Slope efficiencies in excess of 0.06 have been demonstrated. At cryogenic temperatures, while the intrinsic laser efficiency is high, power must be expended on cooling the laser. In some cases operation at room temperature has been achieved. At room temperature, the threshold of the Ho:YAG laser is greatly increased, and slope efficiency tends to decrease. These factors combine to lower the intrinsic efficiency of this laser considerably. At room temperature, little power is expended on cooling the laser; however, the intrinsic laser efficiency is low. At some temperature between these extremes, the optimum total laser efficiency should occur. However, operation at intermediate temperatures has been largely neglected. One exception to this general rule is measurement of the threshold of a Ho:YAG laser as a function of temperature.[3]

To optimize the operating temperature, information on the lifetime, slope efficiency, and threshold were gathered as a function of temperature. A multiply doped Ho:YAG laser rod with concentrations of Er, 0.616; Tm, 0.037; and Ho, 0.021 was used for these experiments. A critically damped 235-s pulse from a Xe flashlamp was used to excite the laser rod. Both flashlamp and laser rod were housed in an Ag-plated elliptical cavity with separate flow channels for the flashlamp and laser rod. Using separate cooling channels and housing the cavity in a vacuum allowed the temperature of the laser rod to be varied while the flashlamp remained at room temperature. In this configuration, laser output energy as a function of the temperature was obtained parametrically as a function of the electrical energy. These data could then be reduced to yield laser output energy vs electrical energy at many different temperatures. In turn, these results could be used to obtain the slope efficiency and threshold as a function of temperature. Both the laser output data and the slope efficiency and threshold as a function of temperature are presented and compared to theoretical expectations.

When considering the total efficiency of the laser, an optimum operating temperature can be predicted using the data on slope efficiency and threshold described above. Total efficiency is a compromise between the electrical power delivered to the flashlamp and the work performed by the refrigerator. Using the data on slope efficiency and threshold as a function of temperature as well as a model for the performance of the refrigerator, the optimum operating temperature for this configuration was found to be ~160 K. These calculations as well as extensions to other configurations are presented. **(12 min)**

1. L. F. Johnson, J. E. Geusic, and L. G. Van Uitert, Appl. Phys. Lett. **7,** 127 (1965).
2. N. P. Barnes and D. J. Gettemy, IEEE J. Quantum Electron. **QE-17,** 1303 (1981).
3. R. L. Remski and D. J. Smith, IEEE J. Quantum Electron. **QE-6,** 750 (1970).

FP5 2-μm room temperature laser operation of Cr:Tm:Ho:YAG

MARK STORM, Sachs/Freeman Associates, 1401 McCormick Dr., Landover, MD 20785; LEON ESTEROWITZ, U.S. Naval Research Laboratory, Washington, DC 20375-5000; MILAN KOKTA, Union Carbide Corp., Washougal, WA 98671.

Efficient room temperature flash-pumped laser operation of the 2.1-μm Ho $^5I_7$–$^5I_8$ transition using Cr:Tm:Ho:YAG is reported. Soviet[1] and German[2] authors have shown the advantage of using Cr instead of Er as the primary sensitizer in ·YSGG. Chromium is an effective sensitizer because it's absorption bands (^2E, $^4T_2$) are strong, and the energy transfer between the Cr ($^4T_2$) and Tm ($^3F_4$) is efficient. In addition, the energy transfer between the Tm ($^3F_4$) and Ho ($^5I_7$) has a quantum efficiency near 2. We report the first U.S. work on Cr:Tm:Ho laser materials showing similar results in YAG.

The YAG crystal used in our experiments was doped with 2.5% Cr, 5.6% Tm, 0.36% Ho. Both the laser rod and flashlamp were 4 mm o.d. × 3 in. long and mounted inside a 3-in. long silver-plated single-ellipse reflector. The xenon flashlamp had a light pulse of 500-μs FWHM. The laser cavity was 45 cm long with a 2.1-μm, 10-m radius of curvature, 99.5% reflecting mirror, and a flat 85% reflecting output coupler. The laser operated with a 67-J threshold and 0.7% slope efficiency.

Previous efforts in flash-pumped 2-μm lasers had concentrated on Er:Tm:Ho doped YAG and YLF. Both materials demonstrate excellent flash-pumped laser characteristics at 77 K. Laser thresholds of <10 J and slope efficiencies between 2 and 3% are common. At 77 K, Er is effective sensitizer because it provides many absorption bands between 0.4 and 1.5 μm that very efficiently transfer energy through thulium to the Ho $^5I_7$. At room temperature the YAG laser threshold is very high due to increased Er fluorescence, strong nonradiative decay processes in Er (which bypass the Ho $^5I_7$), and a thermally populated terminal laser level. The laser threshold increases in the YLF at room temperature primarily because of a thermally populated lower laser level. Because of its thermal loading properties, the YLF host is limited to a few hertz repetition rate at room temperature.

The Cr sensitized Tm:Ho:YAG offers several advantages over the Er sensitized material. The laser threshold in YAG is reduced to 67 J using an 85% R output coupler, which is a factor of ~2 lower than Er sensitized YAG (E_{th} = 120 J). YAG can also handle much larger thermal loads than YLF. This permits the Cr sensitized YAG laser to operate up to 10 Hz compared with 3–5 Hz for Er sensitized YLF. **(12 min)**

1. X. Zharikov *et. al.*, Sov. J. Quantum Electron. **16** (Jan. 1986).
2. X. Duczynski *et al.*, Appl. Phys. Lett. **48** (9 June 1986).

Friday **AFTERNOON**
1 May 1987 **FQ**
ROOM 308

3:00 PM Optical Computing, Storage and Measurement

D. Carlin, RCA Laboratories, Presider

FQ1 Future directions in optical computing: an overview

RAVINDRA A. ATHALE, BDM Corp., 7915 Jones Branch Dr., McLean, VA 22102.

Optical computing information processing is a diverse multifaceted research. In a broad sense it can be said to focus on the use of optical techniques in manipulation of information. The information can be in the form of numbers, 1- or 2-D sensor array signals, or some other abstract symbols representing complex entities. The manipulation can consist of arithmetic operations, signal transformations, or symbol recognition/substitution. The role of optics can vary in extent from a medium of transmission between electronic processing elements to a switching, control, and communication medium in an all-optical system. In the last 5 years optics has attracted increasing attention as a technology for a variety of different roles spanned by these two extremes.

In its 25-year history of active investigations, optical computing has been driven by applications, architectural innovations, or new device/material developments. In the early 1960s, the synthetic aperture radar (SAR) optical processor represented the applications driven system, the VanderLugt matched filter correlator represented the architectures driven system, and some of the early work on injection laser logic symbolized the technology driven system. Out of these major developments, the SAR processor continues to be a viable optical processor. The matched filter correlator in spite of early success suffered from the rotation-scale

Single polarisation operation...

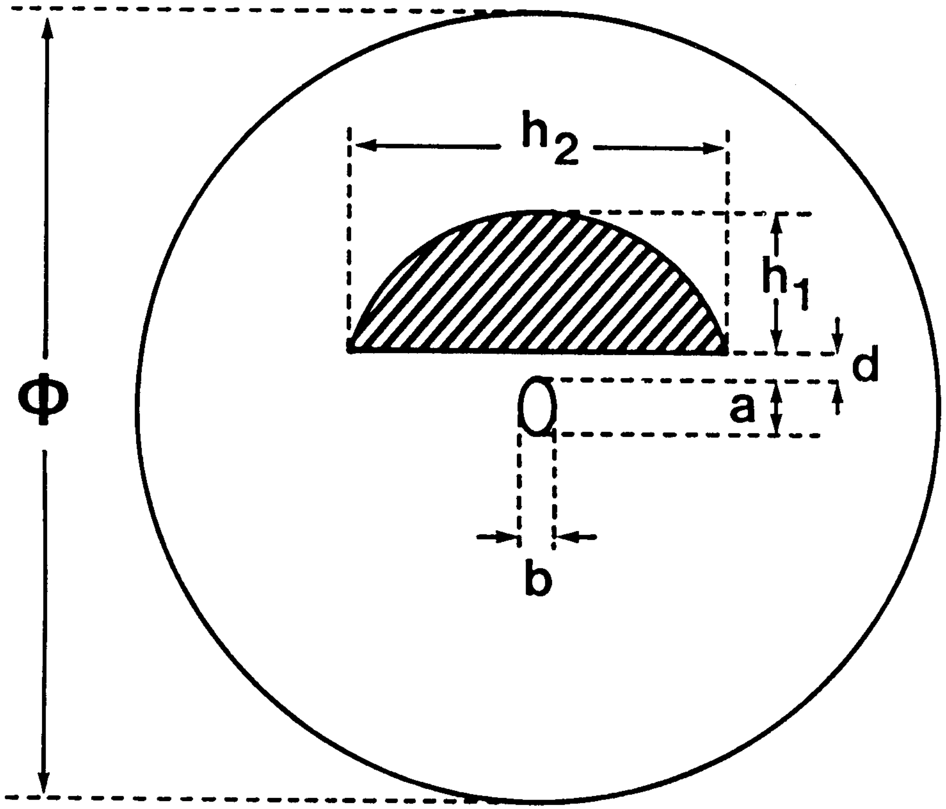
J.T. Lin, L.Reekie and L. Li.

FIGURE CAPTIONS

Fig.1 Schematic cross-section of composite metal/glass Nd^{3+}-doped single-mode fibre.

Fig.2 Single polarisation fibre laser cavity.

Fig.3 Lasing characteristic obtained for cavity of Fig.2.



$\Phi = 120\mu m$

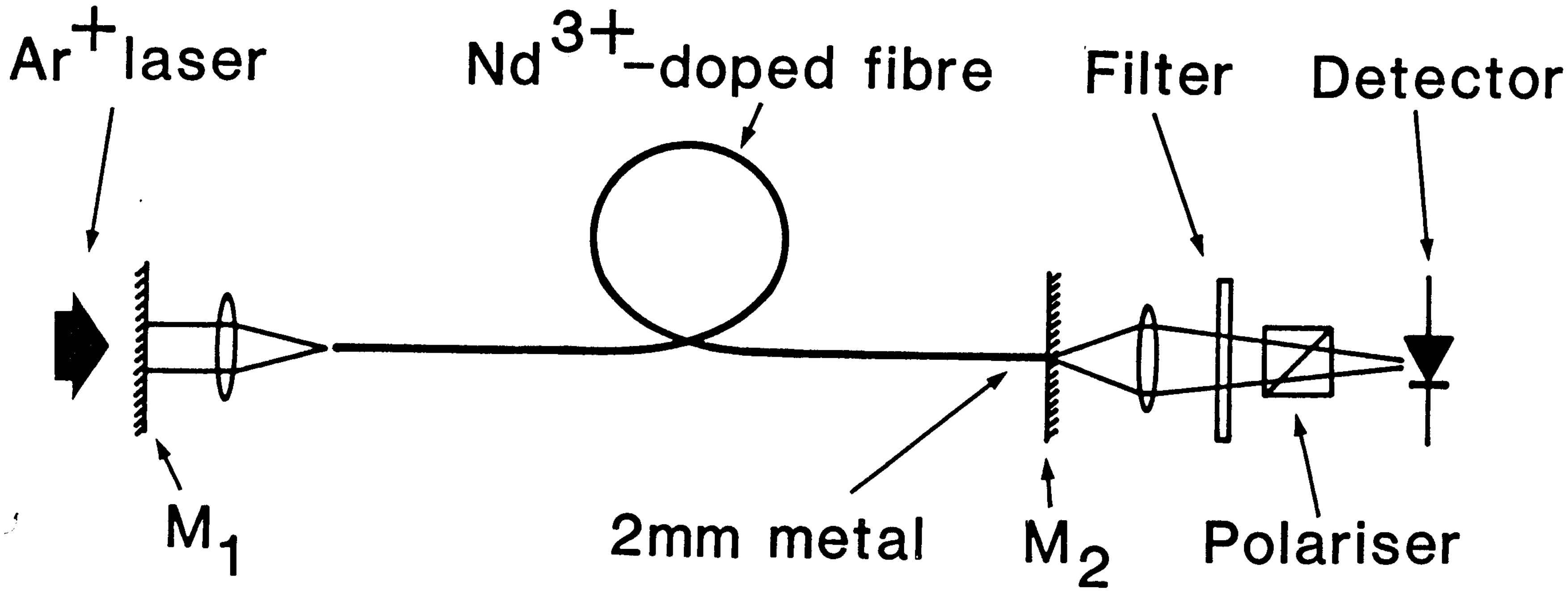
$a = 4.8\mu m$

$b = 3.9\mu m$

$d = 4.0\mu m$

$h_1 = 20\mu m$

$h_2 = 60\mu m$


Ar$^+$ laser
Nd^{3+}-doped fibre
Filter
Detector
M$_1$
2mm metal
M$_2$
Polariser

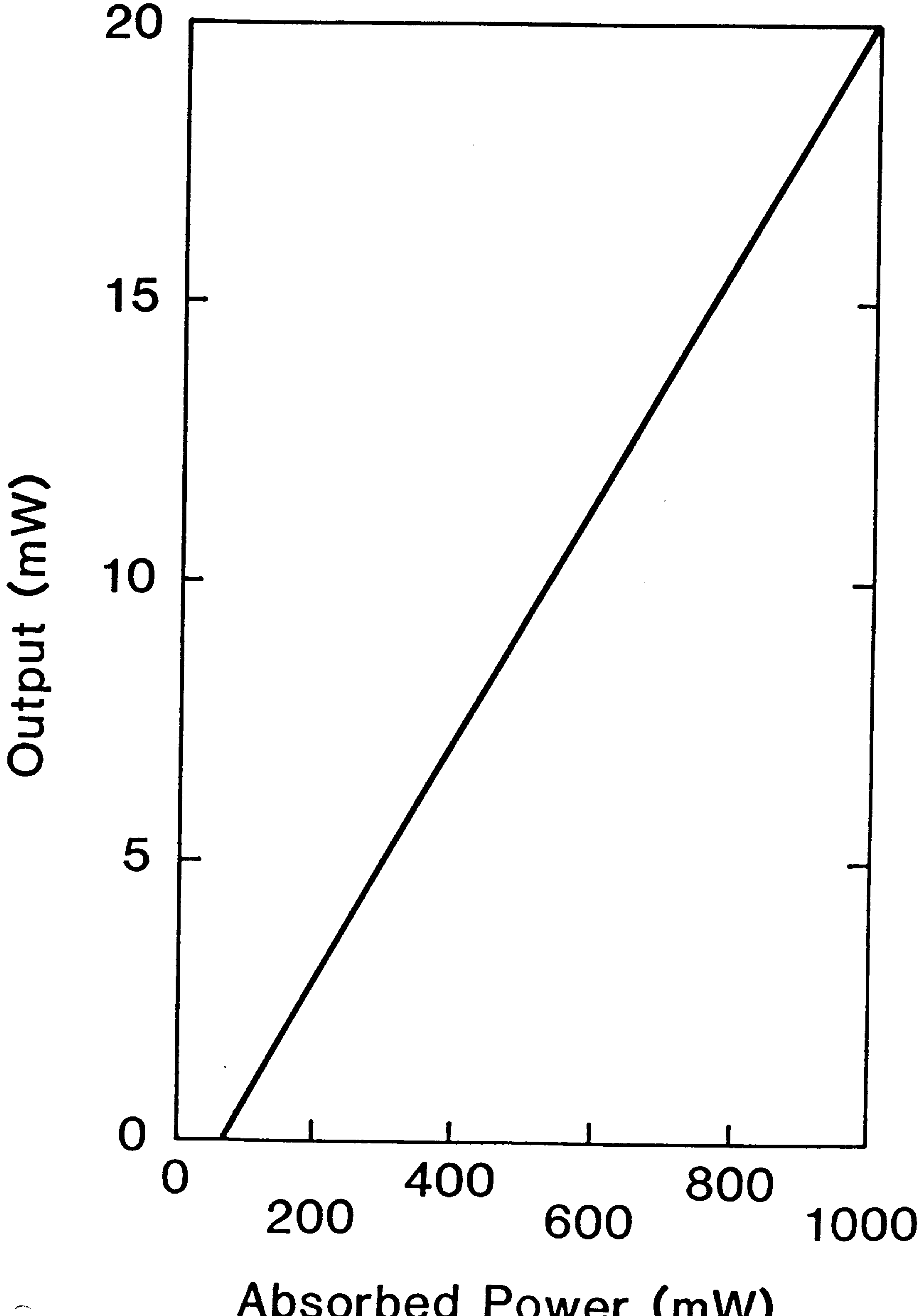


Fig 3