1. INTRODUCTION

'State of the art' capabilities for gas/plasma phase lasers may range from power levels of ~ 2×10^{-2}W for continuous He-Cd lasers to 10^{11}-10^{12}W for pulsed CO_2 lasers. For some purposes high spectral brightness, or the possibility of working at particular (tunable) wavelengths may be of greater consequence than high mean power, although the latter is perhaps the more obvious potential asset of a fluid lasing medium. The object of the present lecture is, therefore, to discuss current applications of 'high power' gas lasers in sufficient detail to delineate the operational characteristics which are most commonly required of such lasers. The applications to be considered fall into four general categories -

(a) Industrial uses
(b) Isotope separation
(c) Thermonuclear fusion
(d) Military applications

These main areas of application will be discussed in the next four sections of the paper, following a sub-division indicated in the first column of Table 1. The most important laser hardware developments will be mentioned in the summary of Section 6, but the means by which the desired operating characteristics are to be achieved will be discussed in ensuing course lectures.

2. INDUSTRIAL USES

2.1 Alignment

The output from a lowest-order mode laser operating with a stable[1] cavity has the Gaussian intensity distribution

$$I(r) = (P/\pi R^2)\exp(-2r^2/R^2) \qquad \ldots(1)$$

where r is the radial distance from the beam centre, P is the laser power, and R is the $^1/e^2$ intensity point. If the beam is transmitted without significant truncation, the full far-field divergence angle to $^1/e^2$ intensities is given by

$$\varphi = 2\lambda/\pi R \qquad \ldots(2)$$

and is less than that for any higher-order cavity mode. A plot of spot diameter versus distance for various lowest-order mode laser-beam (waist) diameters at a wavelength of 632.8 nm is shown in Fig.1. An He-Ne laser beam of $\lesssim$ 1 mW expanded through a telescope to a diameter of ~ 30 mm provides a commonly used alignment aid requiring minimal safety precautions. If the beam centre is established to ~ $\frac{1}{4}$ beam diameter, alignment accuracies of ~ 8×10^{-5} radians are practicable at a range of 100 metres; more sophisticated quadrant detector arrays permit greater angular precision. Using an evacuated system, which avoids refraction errors, an alignment sensitivity of ~ 2.5×10^{-1} mm in 3 km (i.e. ~ $^1/10\mu$ radian) has been achieved in the Stanford linear accelerator.[2]

Since the power requirements are minimal, it is not necessary to use the high-Fresnel-number unstable-cavities which are normally employed to control spatial mode structure (and hence directionality) of a high power beam. The major operational requirements are summarized in successive columns of Table 1; the ideal laser should clearly be cheap, reliable and rugged.

2.2 Raman Scattering

Raman scattering techniques[3,4] are used to make remote temperature and impurity/pollution measurements, and to determine the molecular structures of 'difficult' samples such as (explosive) NCl_3, high temperature melts, cryogenic (or locally orientated) polymer samples, adsorbed surface layers in electrolytic cells, etc. A monochromatic laser line (e.g. $\lambda_o = 4860\text{Å}$) in a convenient, but arbitrary, region of the visible spectrum is most commonly employed for laboratory work, since the Raman spectrum appears as side-bands on the fundamental frequency (c/λ_o). Because of the low scattering cross section, the scattered intensity is typically only 10^{-7} of the incident intensity, so that ~ 10^5 W/cm^2 should be applied to the sample to provide a detected signal of a few counts per second. For more remote measurements, λ_o may be chosen to provide enhanced (resonance) scattering for selective lidar systems (e.g. to measure parts per million of SO_2 emitted from smoke stacks). For remote applications high beam directionality, i.e. high spatial mode control, is important.

2.3 Laser Doppler Velocimeters

The very narrow band width of gas lasers also permits the measurement of low directional velocities ($\ll 10^{-2}$ m/s) by optically heterodyning the Doppler-shifted scattered light signal against a stabilized single-frequency laser transmitter. Typical applications include the measurement of the speed of aluminium extrusions, and hot steel rods.[5] Highly localized velocity measurements of fluid and particle flow rates are also possible; provided the fluid has many scattering particles within the measurement volume rapid changes in local velocity can be measured by using a suitable tracking receiver, in which a variable-frequency oscillator is locked to the mean signal. He-Ne systems measuring fluid velocities of 10^{-2} m/s to 50 m/s have been developed;[6] if the scattered signals are very weak, seeding with particulate material such as polythene spheres can be employed, or higher-power argon-ion lasers utilized. Supersonic velocities can also be determined by measuring larger Doppler shifts with scanning Fabry-Perot techniques.

2.4 Thermo-Mechanical Materials Processing

The time-dependent solution of the heat diffusion equation for a circular laser beam of uniform intensity and of radius a, incident along an axis (z) perpendicular to the flat surface of a semi-infinite medium is given by[7] -

$$T(z,\tau) = \frac{2Fo}{K}\sqrt{\kappa\tau}\left\{\text{ierfc}\left\{\frac{z}{2\sqrt{\kappa\tau}}\right\} - \text{ierfc}\left\{\frac{z^2+a^2}{4\kappa\tau}\right\}^{\frac{1}{2}}\right\} \qquad \ldots(3)$$

where T = the (axial) temperature rise after a heating pulse of duration τ

z = 0 defines the flat surface

Fo = the energy flux absorbed in a surface layer (usually $\lesssim$ 1 μm deep)

K = the thermal conductivity of the medium (of density ρ)

κ = $(K/\rho c)$ the thermal diffusivity of the medium, and

c = the specific heat

When $a \gg \sqrt{\kappa\tau}$ (the characteristic thermal depth) and z, a one-dimensional conduction model is adequate, and the surface temperature rise becomes

$$\Delta T = \left\{\frac{2Fo\sqrt{\kappa\tau}}{K}\right\}\text{ierfc}(o) = \frac{2Fo}{K}\left\{\frac{\kappa\tau}{\pi}\right\}^{\frac{1}{2}} \qquad \ldots(4)$$

The depth at which the temperature rise is only $\frac{1}{2}$ that on the surface is given by

$$\Delta z = 0.68(\kappa\tau)^{\frac{1}{2}} \qquad \ldots(5)$$

If the heating pulse is switched off at all times $t > \tau$, the initial cooling