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Variable Output-Coupling Far-Infrared Michelson Laser

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This paper describes a method for extracting energy from far-infrared gas lasers that has none of the disadvantages of the usual hole-coupling schemes. The method employs a Michelson interferometer configuration with a polyethylene or polypropylene beam splitter. A simple film beam splitter had been previously used by a group at NPL.[1] The configuration is similar to the Smith[2] mode selector; however, the beam splitter is perpendicular to that in the Smith type and it uses identical mirrors at the beam-splitter end. Some of the advantages are (1) diffraction losses are kept to a minimum because the full internal beam diameter is utilized; (2) mode distortion is minimized; (3) the coupling may be continuously adjusted from zero to four times that of a simple beam splitter; (4) the output coupling is easily varied; (5) line identification is simplified as will be explained later; (6) the output beam is linearly polarized, a useful feature in some applications, such as in coupling to the whisker diodes used in frequency measurements[3]; (7) finally, the device is relatively easy and inexpensive to build.

Figure 1 shows the design we have successfully employed for H_2O and HCN lasers operating from 28 to 373 μ. The flat mirrors A and B can be translated by micrometer heads with a resolution of about 0.2 μ. Mirror B serves to tune the resonator B–C, mirror A to vary the power coupled out of the polyethylene lens (the lens may be replaced by a flat window if a focused beam is not

Table I. Powers available from H_2O and HCN Michelson lasers. The lasers were 8-m long and of folded confocal geometry. The power was measured with a "aquadag" blackened copper cone calorimeter.

Laser	$\lambda(\mu m)$	Inside diameter (mm)	Power (mW)	Gas mixtures
HCN	337	133	150[a]	Methane and ammonia
HCN	311	133	50[a]	
H_2O	118	75	20	H_2O vapor and helium
H_2O	79	75	15	
H_2O	78	75	40	
H_2O	28	37	450 (multimode)	

[a] The HCN laser discharge was adjusted for maximum spectral purity and not maximum gain. Good spectral purity is evidenced by stationary striations in the methane and ammonia discharge.

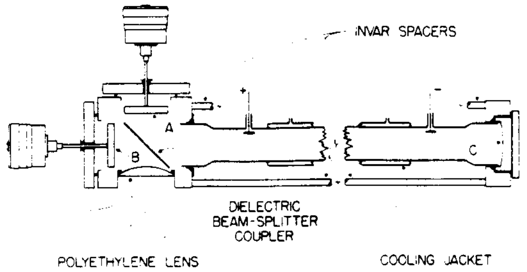

FIG. 1. Schematic drawing of HCN and H_2O variable coupling far infrared lasers. The HCN laser does not have a cooling jacket.

desired) by varying the relative phase of the waves returning to the beam splitter from mirrors *A* and *B*. Since resonator *AC* has such a low *Q*, frequency pulling by *AC* is negligible. The dielectric beam splitter, which is set at an angle of 45° to the laser tube axis, is a taut polyethylene or polypropylene membrane of such a thickness that provides constructive interference of the beams reflected from each of its surfaces. This thickness[4] is an odd multiple of

$$t = 1/4\lambda_0(n^2-\tfrac{1}{2})^{-1/2}, \qquad (1)$$

where λ_0 is the vacuum wavelength of the laser radiation, and n is the refractive index of the polyethylene or polypropylene (about 1.5). For example, our HCN laser ($\lambda_0 = 337\ \mu = 13.3$ mil) has a membrane 2.5-mil thick. The H_2O laser ($\lambda_0 = 28\ \mu = 1.1$ mil) uses a membrane approximately 0.6-mil thick, which is about 3 times the value given by Eq. (1), since we were unable to obtain thinner polyethylene or polypropylene film of suitable quality.

As an example of the operation of the coupling control, we show in Fig. 2 recorder traces of the power coupled out of an HCN laser (337 μ) as function of displacement of mirror *A*, with laser tube current as parameter. When the two waves recombining on the beam splitter are 180° out of phase, there is practically complete cancellation of the output at any current setting. Halfway between, where constructive interference is at a maximum, the laser is actually overcoupled, a desirable condition since one is then sure of obtaining maximum laser output at some intermediate setting of mirror *A*. If the laser gain is not high enough, there will be no oscillation in the overcoupled region. This is seen in the figure at laser currents of less than 0.2 A, and is the normal situation with the 78- and 118-μ lines of the H_2O laser. The water-vapor laser oscillates only on the 28-μ line unless the three mirrors are all precisely aligned. Table I shows the powers we have been able to obtain from various lasers using this coupling method. The side mirror has also proved useful in simplifying line identification. With mirror *B* fixed, one need only measure the translation of mirror *A* from one 180° phase point to the next as on Fig. 2.

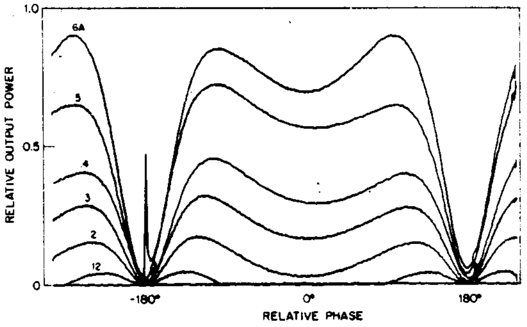

FIG. 2. Recorder traces of power coupled out of an HCN laser (337 μ) by the device of Fig. 1 as a function of the relative phase of the waves reflected from mirrors *A* and *B*. The parameter is laser tube current. A power meter was connected to the *Y* axis of the recorder, and a transducer giving a signal proportional to the displacement of mirror *A*, to the *X* axis. The transient spikes appearing at the 180° positions are caused by mode jumping in the laser.

The power reflectivity of the film at these wavelengths is about 4% so that the maximum fraction of power coupled out of the laser is about 16%. This can be increased even more, if the laser gain permits, by using a compound beam splitter; that is, two parallel membranes with the appropriate interspace between them.

A disadvantage of this scheme which we have noticed is the tendency for drumhead resonances to appear in the membrane if the plasma current is modulated. These can be eliminated, but at a sacrifice of output power, by using a much thicker membrane.

Construction notes and detailed drawings are available in a separate publication.[5]

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