CONF-800138--1



# The Evaluation of a High Power Submillimeter Pulsed Laser System

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operated by
Union Carbide Corporation
for the
U. S. Department of Energy

As an initial step in investigating the use of the Thomson scattering of a submillimeter laser beam as a diagnostic technique for determining plasma ion temperatures, we have designed, developed, and evaluated a submillimeter oscillator-amplifier system to act as a coherent light source for the experiment. The far-infrared (FIR) laser developed was required to have a power level of at least 1 MW, a full width at half maximum (FWHM) of less than 30 MHz, and a pulse length of at least 200 ns. This report describes the selection, development, and testing of the system components and presents the power and frequency profiles achieved in tests made on the assembled system. These results, and knowledge gained through design and development work, have suggested improvements in design characteristics to be applied to future research on this diagnostic method.

The necessity of delivering 1 MW of laser power in 200 ns translates to the storage of a minimum of 200 mJ of energy in the working molecules. At the time the system was initially designed, the most likely lasing molecule was $CH_3F$. Since measured absorption of $CO_2$ pump radiation by $CH_3F$ indicated that $\sim$ mJ/l of energy would be stored in this molecule at operating pressure, the length of a linear amplifier that is pumped by a 10-cm diam $CO_2$ laser beam has been estimated at $\sim$ 30 m, making a linear amplifier unsuitable for the present experiment. Alternatively, a beam-expanding submillimeter amplifier was designed and constructed. It consisted of two f/1 confocal parabolic pairs, one of which expanded an incoming beam of

10 cm to 50 cm. After traveling through 100 cm of amplifier length, the expanded beam was compressed back to a 10-cm beam by a second pair of parabolas. Thus, 250 l of amplifier volume took up only 1 m of length.

The selection of an oscillator to drive the amplifier was made on the basis of the large fundamental mode volume property of the unstable resonator and the reduced higher order modes in this type of oscillator. Additionally, when the power is coupled out diffractively in an annulus around the output mirror, this oscillator is an excellent match to the amplifier.

Another essential component that had to be developed was a tunable source of $CO_2$ pulsed power, which was needed to optically pump the working molecules. The conversion losses in the optical pumping were estimated to be factor of $10^3$, which required that, in order to produce 100-200 mJ of FIR power, the $CO_2$ pulsed laser must deliver 100-200 J.

Fundamental to the production of submillimeter radiation is the laser used to optically pump the molecular gas. The existing $CO_2$ laser technology and its ability to select high power oscillations in the 9-10-μ region made it the natural choice for the optical pump. A commercially available pulsed, $CO_2$ laser met the specification of output power, but was not tunable, nor was the pulse duration the required 200 ns. This inability to be tuned is due to the high power level imposed on the dispersive optical elements within the $CO_2$ oscillator cavity. Tunability could have been achieved by resorting to an oscillator-amplifier system in which a low power oscillator drives a powerful amplifier. However, our solution was to produce tunability in the oscillator itself. This was accomplished by first introducing large cavity losses with an intracavity gas cell containing a few torrs of $SF_6$. The cavity losses at the desired frequency were then minimized by the bleaching action of a cw $CO_2$ laser output injected into the pulsed laser cavity. Among the advantages of this method for tuning are laser efficiency and reliability as well as satisfactory line shape, pulse duration, and mode selection.

Experience with this laser has confirmed its reliability and efficiency properties. Measurements of the frequency and time profiles of the output show that the gain of the oscillator takes the shape of the cw line profile and that the frequency profile of the high power pulse is 20 MHz or less. A photon drag detector and a Tektronics 7912 transient digitizer were used to record the data, and the Tektronics computer and software were used to Fourier transform the data in order to extract the frequency information.

The use of the transient digitizer and computer system provided results which clarified the relationship between injected cw $CO_2$ power and the pulsed outputs. Without injection, the peak power output of the $CO_2$ laser had a value of 140 arbitrary units and a FWHM value of 60 ns. The product of these values is proportional to the energy in the pulse and has the value of $8.4 \times 10^3$. Injection of cw $CO_2$ reduced the value of this product to $2.5 \times 10^3$, where it remained constant for injected powers up to 20 W cw. The peak power dropped by a factor of 3 for weak injected power and by a factor of 10 for 20 W of injected power. This peak power reduction is accompanied by an increase in the FWHM of the pulse by the same factors. Pulses of the order of 150 ns were observed under these conditions.

Control of the frequency of the pulsed output by the cw injected power was also observed as a smooth time domain pulse. For weak injection, only the leading edge of the pulse is smooth, and though the pulse continues to oscillate at the injected frequency it develops a broad frequency profile of ∿ 300 MHz, characteristic of the untuned oscillator. Increasing the level of injected cw power results in extending the time of narrow frequency control up to 150 ns.

The conclusion to be drawn from these observations is that the tunable, pulsed, $CO_2$ laser will provide 60 J of narrow frequency (FWHM < 20 MHz) pump energy in a 150-ns pulse. Furthermore, the operation of the laser is uncomplicated and reliable.

Several general conclusions may be drawn on the basis of our evaluations and analysis of the unstable resonator and beam-expanding amplifier-high power laser system. First, the oscillator was found to be very efficient and to have the proper frequency characteristics. However, the amplifier did not meet the requirements because the amplification of a Raman transition is power dependent, making the expansion of the beam and consequent reduction of power density counterproductive. Also, the far field beam profile of an unstable resonator depends upon a diffractive recombination of the annular near field beam. An optic, such as the amplifier, placed in the near field of the oscillator must meet surface and angle tolerances characteristic of an interferometer in order to permit proper recombination of diffracted amplitudes and phases. This results in an unusually sensitive alignment requirement for the amplifier.

A further deficiency of the tested diagnostic was due to the fact that the combined oscillator-amplifier system, consisting of the unstable resonator and 5 m of 6-in. diam amplifier, has inherent flaws in the frequency characteristic that make it unsuitable as a Thomson scattering laser source. Although this system does produce the required power level, it suffers from superradiance because of the amplifier length.

It would appear that the length of a high power laser system needs to be made a secondary consideration. Since an oscillator is an excellent amplifier, a linear oscillator of sufficient length (3-5 m) would be a proper choice to produce a laser source of 1 MW power with a FWHM of 30 MHz. The spurious multiple longitudinal modes anticipated with the use of a linear oscillator can be controlled by dispersive or absorptive methods. Further, our experience indicates that, with appropriate modifications, an injection-tuned $CO_2$ pump laser may be used to achieve the required 200-ns pulses.

Based on information gained from this first of a series of experiments, additional design and development work is proceeding on the coherent light source as well as on other aspects of the Thomson scattering diagnostic system.

This research was sponsored by the Office of Fusion Energy of the U. S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.