Design and Construction of a Q-switched Laser[1]

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A research program at Oklahoma State is concerned with analytical and experimental studies of dense plasmas. In this program, a tentative equation of state was developed for a plasma which covers a wide range of densities and energy contents (Bruce, 1966). The equation of state for plasmas was developed for the material that has attained a high specific energy content by compression in a hypervelocity impact. A plasma is also produced by the incidence of the giant pulse from a laser on a metal surface (Vogel and Backund, 1965; Gregg and Thomas, 1966). In the latter plasma, interaction of light with matter is tremendously more important than for the plasmas from hypervelocity impact; but the equation of state must be applicable to both plasmas. To obtain experimental

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plasmas with a laser for checking the equation of state, a laser assembly was designed and constructed to obtain a giant pulse. By the Q-switching of a two-ruby laser, a well-formed output is obtained to facilitate future analytical work. In Q-switched operation, a well-designed and accurately aligned laser with these ruby rods and with the available excitation should have a peak power level of several hundred megawatts.

ASSEMBLY AND DESCRIPTION OF THE OPTICAL COMPONENTS

Before the structural design is described, the optical components are discussed—their physical characteristics, physical arrangement and optical interaction with each other. Two rubies, each ½ inch in diameter and 6 inches in length, are mounted one above and one below an opaque chemical solution that bleaches with incidence of the giant pulse. This chemical solution is called the Q-switch. The relative position of these components and the optical flat at the bottom of the laser assembly is illustrated by the sketch in Figure 1. The faces of all optical components that transmit light are flat to 1/10 wavelength.

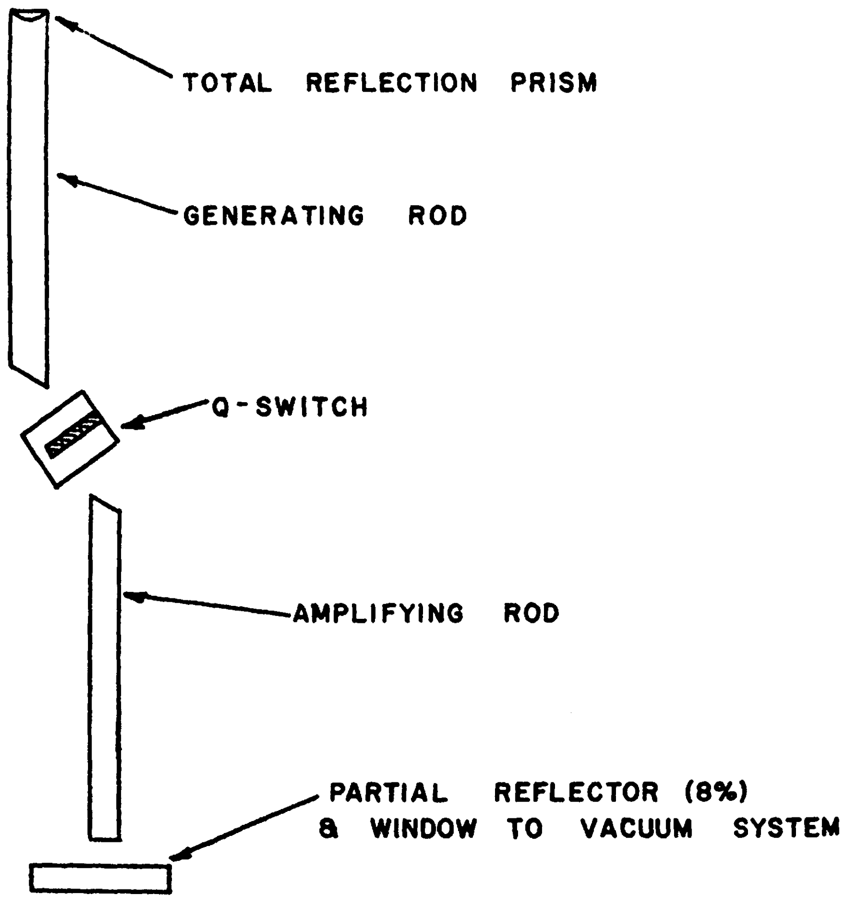

Figure 1. Physical arrangement of the rubies and Q-switch.

The upper, or generator, ruby has a total reflecting prism as its top. The lower end of this ruby is cut with a Brewster angle, and consequently passes only light that is polarized. The Q-switch is placed between the upper and the lower ruby. The lower ruby is an amplifier and receives the light in the giant pulse from the upper ruby through a matching Brewster angle. The amplified light is ejected from the lower face of the amplifier ruby. This face is normal to the light and the ruby-air interface reflects about 8% of the intensity back into the ruby as the light leaves this face. An optical flat is placed at the lower end of the laser chamber. This flat is also the entrance for the light into an evacuated vessel in which the light of the giant pulse strikes a metal surface. Each face of the optical flat is true.

The Q-switch is a quartz cell with optically flat and parallel faces 1 mm apart. It is presently filled with a solution of cryptocyanine in methanol. The concentration is 9×10^{-4} molar. The reflectance of the empty cell is about 16%, but that of the filled cell is only approximately half of this value. The 1 mm layer of the dilute dye is opaque to low intensities of light (Kaflas et al., 1964).

While the Q-switch is opaque, a population inversion is produced among the energy levels in the two ruby rods by two flash lamps. The giant pulse starts in the upper ruby, for it undergoes practically no light loss through the total reflecting prism at the top and the Q-switch at the bottom. In contrast, the lower ruby loses light through the optical flat at the exit from the laser chamber. It has been shown that the greatest intensity is obtained in the giant pulse when the reflectivity of the exit window is the minimum value for which the giant pulse may be obtained and this is the reason for keeping the reflectance near 8%.

The two rubies are excited by two helical xenon flash lamps. Each flash lamp is excited by a bank of condensers with an energy output of 26 kilojoules at 10 kilovolts. The helical flash lamps are not highly efficient in exciting the rubies, but they do give a relatively uniform intensity of radiation across the section of the laser rods. An inductance of 80 microhenries is placed in series with each flash lamp to limit the steepness of the current wavefront from the condensers. A very steep wavefront will shatter the helical tubes. With our low-capacity charging system, it requires about 40 min to prepare for each giant pulse.

Design and Construction of the Mechanical Structure

The maximum energy is obtained in the giant pulse only when almost perfect optical alignment is obtained. The required accuracy is determined by the quality of the ruby rods. For our rods, the inherent divergence is about 0.5 milliradians. For this reason, stability and reproducibility of the adjustments is sought. To assist in obtaining this stability, the components are fixed to a substantial steel platform. This platform is placed between the rubies to keep the adjusting arms short. The system is mounted to have the laser beam projected vertically downward into an evacuated vessel. This design is required to employ our spectrograph for the far-ultraviolet in obtaining spectrograms of the radiation from the plasma.

The design employs the normal face of the amplifier ruby as the reference to which all other optical components are aligned. The mounting and alignment of the components is started by rigidly fixing the amplifier ruby with respect to the steel platform. The generator ruby is mounted above the steel platform and is positioned both translationally and angularly. The lower end of the generator ruby is given horizontal translation and rotation about a vertical axis by means of four differential screws, which have their axes horizontal and parallel to the steel platform. The generator ruby is tipped with respect to the vertical by means of three additional differential screws which have a vertical axis. All differential screws have a coarse advance of 0.03 inch per revolution and a fine adjustment of 0.001 inch per revolution.

The alignment of the optical flat at the entrance to the evacuated chamber is obtained by three differential screws that are attached to the bottom of the case for the amplifier ruby. The cell for Q-switching must also be inserted and angularly aligned in order to be normal to the laser beam. This is accomplished by two differential screws which move a cantilever with respect to the reference steel platform. The alignment of all optical components is obtained while observing auto-collimation and auto-reflection.

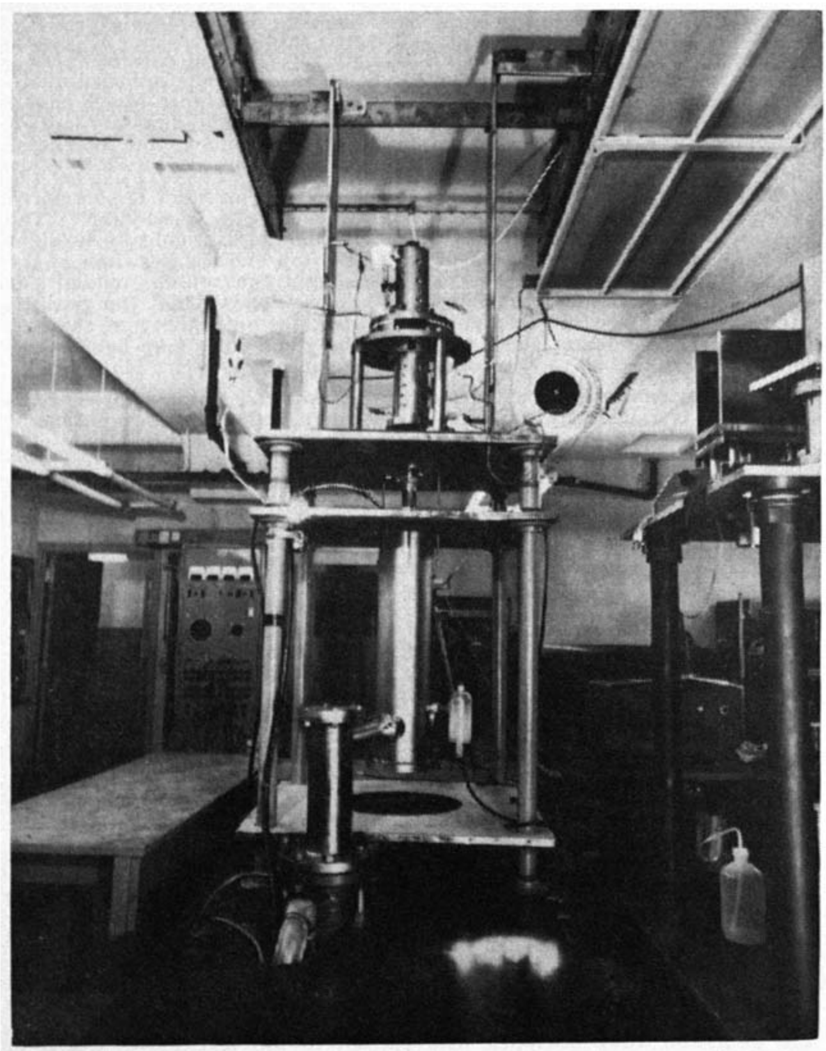

Figure 2. Assembly of the giant-pulse laser.

After this detailed description of the alignment of the components, the overall assembly may be more easily described. The rubies are mounted in the two perforated cylinders which appear above and below the steel platform (Figure 2). The perforations permit the escape of air that is heated by the flash tubes. The steel platform is shown in relation to the other components at the top-center of the picture. The two condenser banks are on the ceiling at the top right and left in the picture. The long cylinder immediately below the laser cases is the evacuated vessel for the laser beam impingement on the metal surface. The connection from this case to the diffusion pump appears in the center foreground. The two flat coils to the right and left of the ruby cases are the inductances to give a current rise time of 0.2 milli-seconds for the flash tubes.

Within the evacuated vessel containing the metal target are a rat's nest calorimeter and a phototube. These measure the integrated energy in the laser pulse and the time variation of the intensity of the laser light,

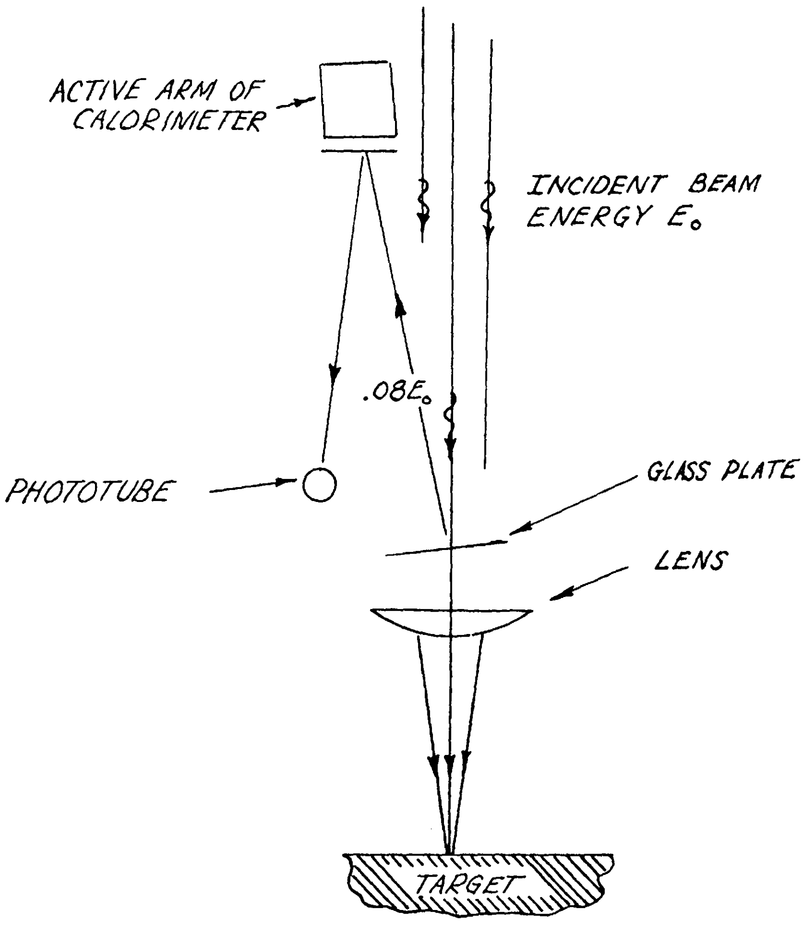

Figure 3. Arrangement of components in the evacuated chamber.

respectively. The arrangement of the components in the evacuated vessel is indicated by the sketch in Figure 3. The glass plate reflects about 8% of the energy in the laser beam into the active arm of the calorimeter while another such plate reflects about 8% of this secondary beam into the phototube. The rat's nest calorimeter (Baker, 1963) employs the change of resistance in a bridge circuit to obtain an integrated measure of the energy content of the laser beam. An active and a reference arm of the bridge consist of 1000 ft each of number 36 copper wire, randomly stuffed into small beakers. One beaker, or bridge arm, is irradiated and heated by the roughly 8% of the light in the original laser beam. The resulting resistance unbalance in the bridge is observed with a galvanometer. Laser beam energies as small as 0.3 joules may be measured.

PRELIMINARY RESULTS

Only a few exploratory tests have been performed up to this time. For these tests, the laser was operated in the conventional mode, in contrast to the giant pulse mode. Only half of the available pump energy of 52 kilojoules has been employed, but this energy exceeds the threshold for laser action. The measured energy in a series of light spikes in a conventional laser pulse was 5 to 10 joules.

Several laser pulses have been made incident on aluminum foil and aluminum plates. Holes are punched through the foil. The crater in an aluminum plate of 0.060-inch thickness is approximately 0.050 inch in diameter. As soon as operation in the Q-switched mode is obtained, the plasma will be studied; one of the first investigations will be made with the spectrograph for the far-ultraviolet described by Payne and Todd (1966).

In conclusion, the authors wish to acknowledge the assistance in construction and operation of this laser by Messrs. W. H. Gurney, L. E. Cochran and W. R. Robinson.

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