A CONTINUOUS WAVE ATOMIC BROMINE LASER PRODUCED BY PHOTOLYSIS OF IODINE MONOBROMIDE

THESIS

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AFIT/GAP/ENP/99M-12

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Wright-Patterson Air Force Base, Ohio

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Abstract

An apparatus to generate continuous wave (CW) lasing at 2.714 μm by $Br(^2P_{1/2})$ atoms produced from photodissociation of IBr was designed, constructed and tested. A frequency doubled Nd:YAG laser firing 8 ns, 850 mJ pulses at 532 nm was used to photodissociate static IBr vapor inside a flow nozzle. The CaF_2 windows on either side of the nozzle proved to have a damage threshold below the threshold for lasing. Pulsed lasing in static mode was not observed. Therefore, CW lasing in flow mode, using an Ar^+ laser at 488 nm, could not be investigated.

I. Introduction

Overview

The Directed Energy Directorate of the Air Force Research Laboratory (AFRL/DE) is interested in a continuous wave (CW) laser for space-based, solar-pumped operations. Proposed applications are propulsion, power generation and transmission, deep space communication, and de-orbiting of space debris (1:6). The high cost of transporting materiel into space necessitates a laser with high efficiency and a non-depleting lasant. The iodine monobromide (IBr) laser, which operates on the $4^2P_{1/2}$ -> $4^2P_{3/2}$ transition of atomic bromine, has excellent potential for space-based applications. The absorption spectrum of IBr closely matches the solar energy flux curve. In addition, iodine and bromine spontaneously recombine after photolysis. However, since demonstrated laser pulse lengths are no more than 50 μs, and the recombination time of IBr is approximately 3 ms, no CW IBr laser has been demonstrated. A solution proposed by Zapata and De Young is to flow IBr through the lasing chamber within the time of a single laser pulse to remove ground state bromine and maintain population inversion (2:1692). This experiment involves a design to implement the proposed solution and produce CW lasing.

Background

Interested in finding chemically reversible lasers, C. R. Giuliano and L. D. Hess demonstrated the first atomic bromine laser in 1968. IBr was photodissociated using a Xe flashlamp powered by 540 J, 12 kV discharges from a 7.5 μF, .04 μH capacitor. Risetime of the flashlamp pulse was 7 μs with a pulse duration of 15 μs at full-width half-max. Two laser tubes with 1.1 m total length were placed between gold-coated mirrors 1.6 m apart, one flat and the other with a 4 m radius of curvature. Lasing at 2.7 μm was observed, which corresponded to the 2.714 μm $^2P_{1/2}$ (Br^*) -> $^2P_{3/2}$ (Br) magnetic dipole transition of atomic bromine (3:2428). Up to 50 W of laser power was achieved, and the gain of the system was approximately 0.2 %/cm (3:2429). Iodine and bromine were observed to recombine into IBr in about 3 ms, which demonstrated chemical reversibility (3:2430). The addition of air, Ar, Br_2, CF_3Br, and N_2 to pure IBr in the laser tube proved detrimental to lasing. An increase in threshold occurred as the ratio of added gas was increased (3:2429).

In 1982, Zapata and De Young investigated the IBr laser as a candidate for a solar-pumped laser. Since the peak of the IBr absorption curve, 500 nm, is at the peak of solar flux and its absorption bandwidth is approximately 150 nm, IBr absorbs about 13% of incident solar radiation. Since the average quantum efficiency of a solar-pumped IBr laser is approximately 18.5%, assuming complete absorption and 100% Br^* production, the IBr laser has a theoretical maximum energy conversion efficiency of 2.5%, which makes it an attractive solar-pumped laser candidate (2:1686).

Zapata and De Young used a xenon flashlamp to coaxially pump static IBr. Maximum output power occurred with 12 Torr of IBr and maximum output energy with 9 Torr (2:1688). A 500 J input to the flashlamp, resulted in peak output power density of 350 W/cm^2, peak energy of 2.5 mJ, and a small signal gain of 0.17 %/cm (2:1692). They found that adding buffer gases to the IBr increased laser pulse length, output power and output energy. Neon produced the longest laser pulses of 53 μs (2:1688). In addition, neon buffer gas decreased the recombination time of IBr tenfold (2:1692). Zapata and De

Young suspected that neon extended pulse length and reduced recombination time by increasing the heat capacity of the gas. The rate of temperature increase in the gas was thus reduced (2:1688). Increased temperature causes the population inversion to suffer by slowing the process of depleting the lower laser level through the recombination of iodine and bromine (2:1692).

Despite these improvements, the IBr laser of Zapata and De Young would not lase CW. The laser will, at best, lase for 50 μs and recover for 250 μs. Therefore, $5/6^{th}$ of the solar energy incident upon such a pulsed laser could not contribute to lasing, requiring reestimation of the energy conversion efficiency of a solar-pumped IBr laser. The 2.5 % estimate of Zapata and De Young assumed CW lasing. If $5/6^{th}$ of the incident solar energy is lost due to the duty cycle of the laser, the maximum energy conversion efficiency is only 0.4%, which is below NASA's projected low-end requirement of 1% (1:10). Therefore, an IBr laser will probably need to be made to operate continuously if it is to be used as a space-based solar-pumped laser.

Zapata and De Young do not think that a CW laser is possible with a static filled chamber. However, they suggest that if IBr gas flows through a lasing chamber in less than 50 μs and is allowed enough time to cool and recombine before reuse, then CW lasing could be achieved (2:1692). Harries and Meador, who performed kinetic modeling of an IBr laser, agree that CW lasing may be possible with a continuous flow system (4:201). Their research shows that under solar-pumped operation, the temperature of the lasant would increase several hundred degrees K within 50 μs (4:196). Therefore, temperature rise may be the most stringent requirement for quickly flowing lasant through the lasing chamber. Their research indicates that the exchange reaction Br + IBr

$= I + Br_2$ is vital to removal of ground state bromine. Without the reaction, suggest Harries and Meador, lasing would not occur. Also extremely important mechanisms in IBr laser dynamics are quenching of Br^* by IBr and I (4:197). Harries and Meador suggest that a solar-pumped IBr laser could reach an efficiency of 1.2 %, slightly more conservative than Zapata and De Young (2:201).

Haugen, Weitz and Leone determined the quantum yield of Br^* production from photodissociation of IBr at wavelengths from 450 nm to 530 nm (5:3402). Quantum yield is more than 60% above 480 nm with a peak yield of 73 ± 2% at 500 nm (5:3412). Since peak quantum yield coincides with the peak of the solar flux curve and the peak of the IBr absorption curve, solar pumping should produce high population inversion. Both a Nd:YAG laser frequency doubled to 532 nm and an argon ion (Ar^+) laser at 488 nm produce a quantum yield of 70 ±2%, making them effective photolysis sources (5:3412).

In 1996, Ray Johnson detailed the dynamics of an atomic bromine laser (6:5). A 90 cm long, 1.3 cm diameter glass tube, capped by Brewster's angle windows of CaF_2 or BaF_2, was filled with IBr vapor at 0.9 to 6.5 Torr (6:6-7). Two gold-coated mirrors separated by 1.5 m, one flat and one with a 5 m radius of curvature, formed the laser cavity. The system was longitudinally pumped with a Nd:YAG laser, frequency doubled to 532 nm, firing 20 Hz, 10 ns pulses with 25-125 mJ per pulse. The photolysis beam entered the gain cell with a 4-8 mrad crossing angle, resulting in an effective gain length of 41 cm (6:6). The threshold for lasing was 20-25 mJ of photolysis energy (7:121). The gain reported was 0.9 %/cm. The pulse length of the laser was 2 μs. Maximum energy output occurred with 2.5 Torr of IBr (6:5).

Lasing was reported by Anderson, Miller and Hager in a transversely pumped IBr laser where 135 mJ pulses from a Nd:YAG laser excited a gain region 3 mm in diameter by 4.5 cm in length (8:604). A 5 m radius of curvature high reflector and a flat 90 % reflective output coupler were placed 22 cm apart to form the laser cavity (8:604).

Problem Statement

Even a more liberal estimate of the efficiency of a solar-pumped IBr laser indicates that, unless an IBr laser is made to lase continuously, IBr will not be an effective lasant for a space-based solar-pumped laser. A solution has been proposed, but no attempt has been made to build a CW IBr laser with a flow nozzle. The purpose of this thesis is to break ground in the area of research into a flow system for a CW IBr laser and, if possible, demonstrate a CW IBr laser.

II. Experimental Apparatus

Gas-Handling System

The apparatus used to perform this experiment is shown in Figure 2.1.

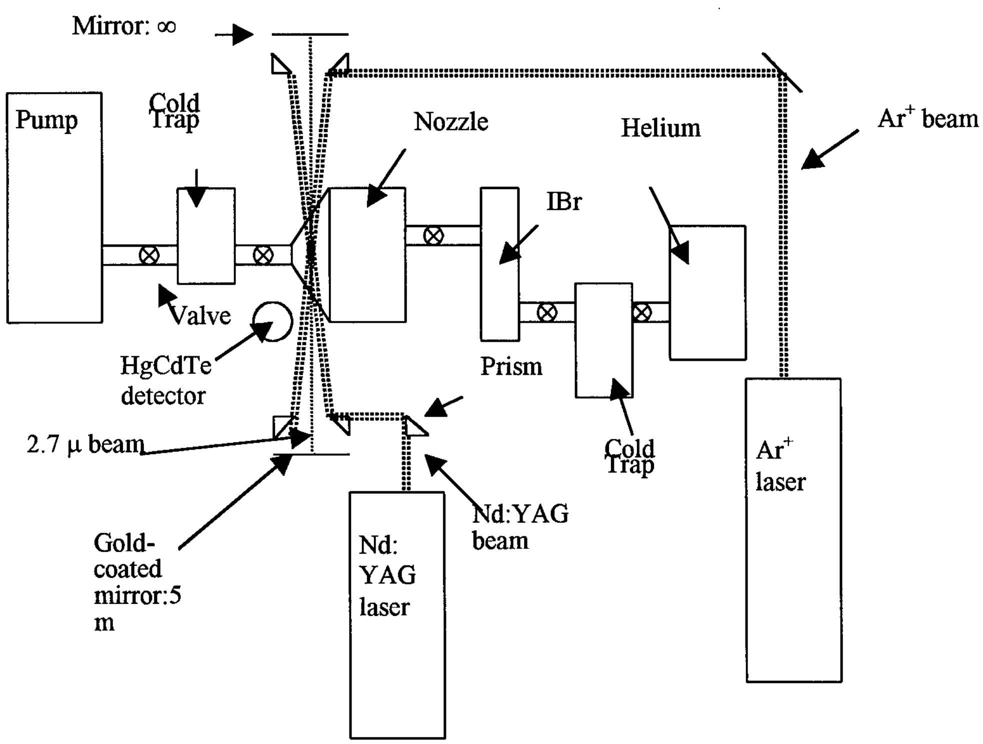


Fig. 2.1. Experimental setup.

An Alcatel 2063 CP+ chemical vacuum pump creates low pressure to pull IBr vapor through the nozzle. The pump provides 50 cfm free air displacement and an ultimate pressure of $5x10^{-3}$ mbar. In static mode, the pump creates a vacuum of 50 mTorr inside the nozzle. An MDC KDFT-6150 liquid nitrogen cooled foreline cold trap collects IBr vapor after it passes through the lasing chamber but before it enters the pump intake. The lasing chamber is located inside a stainless steel nozzle, shown in Figure 2.2. The wall of the outer housing of the nozzle is sloped at 54.8°, Brewster's angle for 2.7 μm energy incident on calcium fluoride (CaF_2). CaF_2 windows set into the wall of the nozzle form the ends of the lasing chamber. The inner housing of the nozzle is capped by a slit plate.

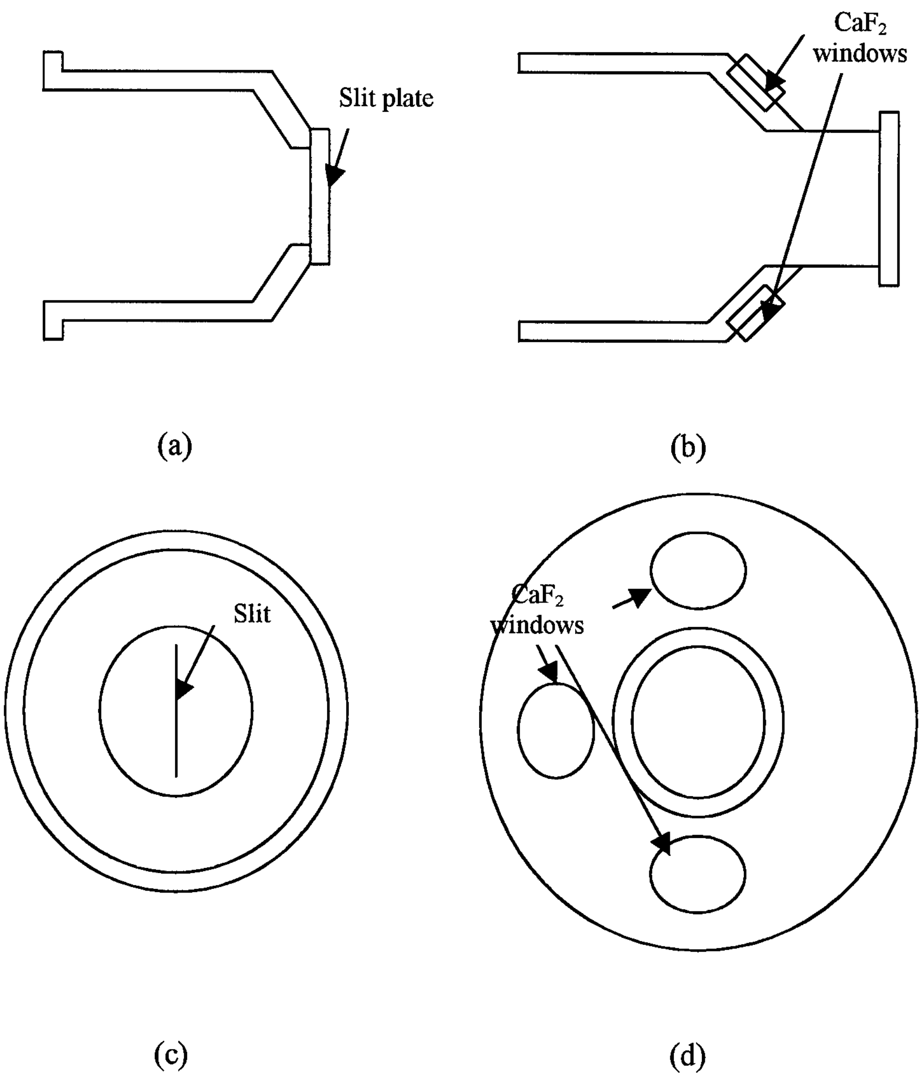


Fig. 2.2. Flow nozzle: a) inner housing, top view, b) outer housing, top view, c) inner housing, front view, and d) outer housing, front view

The slit, on the front side, near the vacuum pump, is 1.4 in long and 1 mm wide. The plate is 0.25 in. thick, with the slit width expanding at 45° to 0.54 in. on the back side, away from the vacuum pump. Two MKS Instruments Baratron pressure gauges, a 0-10 Torr gauge in front of the nozzle and a 0-100 Torr gauge behind the nozzle, measure the pressure inside the nozzle to determine pressure differential across the slit plate. Solid IBr is stored in an evacuated glass chamber connected to the back end of the nozzle. A liquid nitrogen cooled glass cold trap allows IBr to be cryo-pumped back through the nozzle for reuse after the IBr reservoir has been depleted. Helium provides additional pressure, if necessary, to accelerate gas through the slit and into the lasing chamber. Valves were placed to allow individual isolation of the cold traps, the nozzle and the IBr reservoir.

Laser Cavity

Two gold-coated, 2 in. diameter mirrors separated by 1.4 m form the laser cavity. Each is approximately 99% reflective for 2.7 μm radiation. The mirror near the entry point for the Nd:YAG beam has a 5 m radius of curvature, and the other is flat. The spot size for the cavity is 1.39 mm at the flat mirror and 1.46 mm at cavity center, where the nozzle is located. In static laser operation, gain occurs along the entire 5 cm length between the CaF_2 windows. During flowed operation, IBr is only directly in front of the slit, so that the gain length drops to 3.5 cm. The $TEM_{0,0}$ mode volume is therefore 0.4 cm^3 during static operation and 0.3 cm^3 during flowing operation.

Optical Pumping System

A Continuum Powerlite 9030 Nd:YAG laser, producing a 1.06 μm beam frequency doubled to 532 nm, provides longitudinal optical pumping for pulsed laser operation. An argon ion (Ar^+) laser, producing a 7 W CW beam at 488 nm, provides longitudinal optical pumping for CW laser operation. The beams are directed through the lasing chamber by four 45° prisms. The prisms are positioned as closely as possible to the center line of the laser cavity and to the gold mirrors of the IBr laser cavity to provide the minimum crossing angle, 8 mrad, without obstructing the IBr laser cavity.

The Nd:YAG laser operates at 30 Hz with a pulse length of 8 ns. The peak energy is 850 mJ per pulse. The spot size is 9 mm in diameter, constant inside the laser cavity. The Ar^+ laser has maximum power of 7 W and a spot size of 2 mm in diameter, constant inside the laser cavity.

Detection System

A Kolmar Technologies KV103 SMA-2 mercury-cadmium-telluride (HgCdTe) detector with a 2.7 μm filter is used to detect the infrared beam produced in the laser cavity. The detector has a 1.6 ns response time and a 3.5 ns rise time. The detector is positioned as closely as possible to the CaF_2 window near the entry point for the Nd:YAG beam to detect scatter from the window. The detector signal is fed to a LeCroy 9450 oscilloscope to determine the presence of a laser pulse and to measure its pulse shape.

III. Experimental Procedure

Introduction

In order to create a CW laser system in this experiment, it was necessary to first align the mirrors of the laser cavity using a helium-neon (HeNe) laser directed into the cavity by a beam splitter. After achieving rough alignment, the lasing chamber was evacuated and filled with IBr vapor. Using the Nd:YAG laser to optically pump the IBr, the mirrors were individually adjusted in small increments to form a resonant laser cavity. Had this step succeeded, an attempt would have been made to achieve pulsed lasing with flowing IBr gas, still using the Nd:YAG laser as the photolysis source. Then the Ar^+ laser would have been used as a CW photolysis source. The solid IBr would be heated, increasing the pressure behind the nozzle and thus increasing flow speed through the lasing chamber, until CW lasing was achieved.

Alignment

One iris was placed at each end of the nozzle and a third was placed close to the curved gold mirror. A HeNe laser beam was directed by a beam splitter through one iris and onto the curved mirror. The reflection was directed to pass through all three irises, through the center of the CaF_2 windows of the nozzle, and onto the center of the flat mirror. The second reflection was directed back along the same path. Further reflections were too dim to be seen.

IBr Purification

The concentration of I_2 and Br_2 in pure IBr vapor is 4% each. Excessive I_2 or Br_2 would be detrimental to lasing by quenching excited Br atoms and depleting the upper laser level (4:192). Other atmospheric contaminants, such as water, oxygen and carbon dioxide, will also rapidly quench Br^* (5:3403). To remove contaminants, the IBr was distilled. Solid IBr was collected in a cold trap and frozen by immersing the trap in liquid nitrogen. The vacuum pump was then turned on to produce vacuum in the cold trap. With the pump still on, the liquid nitrogen was removed to allow the cold trap to thaw slowly under vacuum. Since IBr is solid at room temperature, I_2, Br_2 and other gaseous contaminants were removed by the vacuum pump much faster than IBr, leaving pure IBr in the cold trap. The process was repeated several times to improve purity. The level of purity could be seen by the reddish color of the IBr vapor.

Static Testing

The nozzle was first tested without flow to ensure lasing could be achieved. IBr was allowed to fill the evacuated nozzle. The Nd:YAG laser was fired at full power through the CaF_2 windows of the nozzle, and the mirror axes were individually aligned in small increments to perfect the cavity alignment. The HgCdTe detector was positioned close to the CaF_2 window on the photolysis laser side to detect infrared scatter from the Brewster's angle window. The pressure was varied from 2 to 9 Torr in 0.5 Torr increments, with the alignment procedure repeated at each increment. Pressure lower than the vapor pressure was achieved by closing off the IBr reservoir before the pressure inside the nozzle reached the vapor pressure. Since IBr vapor tended to quickly condense on the walls of the nozzle, reducing pressure, to maintain the desired pressure small adjustments were periodically made by quickly opening and closing the valve to the reservoir. Pressure higher than the vapor pressure was achieved by heating the reservoir with heat tape until the desired pressured was reached. When lasing was not achieved at any pressure, attempts were made to increase the flux by focusing the photolysis beam, as reported in the Chapter IV.

Flowing Operation

The speed of sound in IBr vapor can be determined from the molecular weight and specific heat of IBr by using the following equation:

$$a = \sqrt{\gamma R T} \tag{3.1}$$

R_{IBr} is the gas constant for IBr and can be found from the universal gas constant R and the molecular weight of IBr:

$$\mathrm{R}_{\mathrm{IBr}} = \frac{R}{\mathrm{M}} = \frac{8.31\ \mathrm{J/mol\ K}}{.2068\ \mathrm{kg/mol}} = 40.2\ \mathrm{J/kg\ K} \tag{3.2}$$

Gamma is found from the specific heat by:

$$\gamma = \frac{C_p}{C_p - \mathrm{R}} \tag{3.3}$$

The specific heat of IBr is 176.5 J/kg K (9:162). Therefore, $\gamma = 1.29$ and the speed of sound at T = 300°K is 125 m/s. Since the IBr beam waist at the nozzle is 1.46 mm, the speed necessary to clear the lasing region in 50 μs is 58.4 m/s. The speed necessary for CW lasing is less than half the speed of sound in IBr vapor. Therefore, the pressure differential required for CW lasing can be approximated by treating IBr vapor as an incompressible fluid. The nozzle slit acts as a Venturi tube, accelerating the IBr due to a change in pressure and area. The following equation yields the required pressure differential:

$$v = A_1 \sqrt{\frac{2\Delta P}{\rho(A_1^2 - A_2^2)}} \tag{3.4}$$

Assuming the mass density of IBr vapor at 5.5 Torr, 60.83 g/m^3, ΔP = 0.77 Torr is required to achieve 58.4 m/s in the nozzle. If IBr can be made to sublimate fast enough, it may not be necessary to use helium to increase the pressure behind the nozzle.

To test flowed operation, the cold trap near the vacuum pump is filled with liquid nitrogen. Solid IBr is heated to increase the pressure differential across the nozzle slit. The pump is then turned on, and the two Baratron gauges measure the pressure differential. The IBr is photolyzed with the Nd:YAG laser to ensure pulsed lasing is possible during flowed operation. The threshold is determined and the pulse shape is measured for lasing at various flow rates. After demonstrating pulsed lasing in flowed operation, the flow is increased to allow IBr gas to clear the gain region within 50 μs. The Ar^+ laser is then activated as the photolysis source. If the pressure differential cannot be increased to at least 0.77 Torr, then CW lasing is probably not possible without a buffer gas. To raise the pressure behind the nozzle, helium will be allowed into the nozzle, increasing the flow rate across the lasing region. The IBr is heated to increase partial pressure until lasing occurs or maximum IBr partial pressure has been reached. If CW lasing has not been achieved, the Nd:YAG laser would be activated in conjunction with the Ar^+ laser and the flow rate would be varied. The pulse shape of the infrared beam is then examined for effect by the CW photolysis beam. Expected effects of the increased photolysis energy are lengthening of the laser pulse or increase in pulse energy.

IV. Results

The nozzle design implemented did not produce lasing in static mode. The experiment did not proceed to flowing operation. The current experiment used a photolysis laser with 850 mJ, 8 ns pulses and a spot size of 9 mm. The flux of the laser was therefore 16.7 kW/cm^2. Since the gain region was 2.9 mm in diameter, approximately 90 mJ per pulse was useful in pumping the IBr laser. Johnson reported threshold of 1.59 to 2 kW/cm^2 when longitudinally pumping a gain region 41 cm in length (7:121). The gain length of the nozzle used in the current experiment was 5 cm, about eight times less than Johnson's system. The power added in a laser oscillator is a linear function of length for a large input signal (10:222). Therefore, due to the shorter gain length, the threshold for lasing in the current system was expected to be approximately eight times the threshold in Johnson's experiment. Anderson, Miller and Hager, who transversely pumped a 4.5 cm gain length with 135 mJ per pulse, did not report the threshold photolysis energy. The power used in the current experiment was 2/3 that used by Anderson, Miller and Hager and eight to ten times the threshold power reported by Johnson. Therefore, the nozzle design and photolysis laser used in this experiment may have been very close to the threshold for lasing under ideal conditions. Many other factors, discussed below, may have contributed to excess loss in the cavity so that lasing was not possible.

Losses in the photolysis beam were approximately 12.5% at each prism and CaF_2 window. Two prisms and one window attenuated the beam before entering the lasing chamber, resulting in 33% loss in the photolysis beam. Johnson presumably suffered the same losses, so there was no reason to conclude that attenuation of the photolysis beam resulted in conditions below threshold.

Attempts were made to increase the useful photolysis energy. Using two confocally placed convex lenses of 70 mm and 25.4 mm focal length, the beam diameter was reduced from 9 mm to 3.3 mm. Unfortunately, the laser ionized the air at the focal point of the 70 mm lens, causing tremendous power loss and lensing effects by the superheated air. The use of a 1 m focal length lens to focus the beam at the center of the nozzle caused ionization of the air all along the length of the nozzle. Had they been in place, the CaF_2 windows would have been destroyed. An attempt to focus the photolysis beam past the nozzle, so that the beam diameter would be approximately 3 mm at the nozzle, destroyed the prism directing the photolysis beam away from the flat gold mirror and damaged the mirror. Focusing the beam before the nozzle was not possible, since ionization of the air would have robbed the photolysis beam of its power before the IBr could be photodissociated.

Focusing the beam would likely have destroyed the CaF_2 windows before lasing was achieved. The average flux of the photolysis beam at full power was 167 MW/cm^2. Examination of the burn pattern, however, showed high-energy rings within the beam. Spot measurements of the beam using a PIN diode detector with a 500 μm diameter showed that the high-energy rings were up to 10% higher in energy than the low-energy rings in between. In addition, an FND-100 detector showed a shot-to-shot variation of ±12%. Therefore, peak flux at the highest energy spots in the beam may have been 20 kW/cm^2. The flux proved high enough to etch a partial ring into one of the CaF_2 windows on the nozzle. The window was kept clean and the damage was done to the outside of the window, indicating incident flux beyond the damage threshold of the window. A more precise determination of the damage threshold of CaF_2 was not possible, since the Nd:YAG laser ceased functioning before such measurements could be taken. However, if the damage threshold of the windows was no more than 25% above the threshold for lasing, the windows were likely to fail before lasing could be achieved.

The amount of H_2O, O_2, and CO_2 contamination still present in the IBr vapor after distillation was not known and may have contributed to quenching. Only H_2O was likely to remain in significant quantity, since the rest are gaseous at room temperature and are removed rapidly by freeze-thaw-pump distillation.

Within a few minutes of being introduced into the nozzle chamber, in the same manner reported by Brennan, a brownish haze began collecting on the inside surface of the CaF_2 windows which contributed to cavity losses (11:186). No solution was found to the haze problem except to frequently clean the windows. Over time, whether or not the windows were kept clean, the photolysis laser created a blackened burn pattern on the inside surfaces of the CaF_2 windows. The burn pattern could not be removed, even with hydrochloric acid. Once the burn pattern appeared on a window, the window was discarded, as losses due to the blackening were presumed too high for lasing to occur.

An attempt was made to lase with IBr in a conventional long cylindrical cell. A glass rod with an inside diameter of 9 mm was capped with two Brewster's angle windows. Sapphire, BaF_2, and CaF_2 were each used. The gain length between the windows was 49 cm. The same experimental setup shown in Figure 1 was used with the glass tube in place of the stainless steel flow nozzle. The tube was filled with IBr vapor. The photolysis beam was passed through the tube, and the gold mirrors were adjusted to improve alignment. The sapphire windows had the highest damage threshold, the CaF_2 windows the lowest. The BaF_2 windows proved most resistant to developing blackened burn marks.

Several problems occurred with this experimental setup. The photolysis beam had to be restricted with an aperture to 4 mm diameter. Otherwise, since the photolysis beam entered the gain tube at an 8 mrad crossing angle, part of the beam was reflected from the wall of the gain tube and focused on the far Brewster's angle window. Two windows were damaged by this accidental reflection. The sapphire and BaF_2 windows had been previously used in IBr experiments. Despite thorough cleaning with acetone and methanol, examination with a Bomem spectrometer showed significant absorption at 2.7 μm by the previously used windows. The contaminated windows produced an unknown amount of loss in the IBr laser cavity. Additionally, at some point in the experiment, optical elements in the photolysis laser were damaged, apparently by backscatter from one of the lenses used to focus the photolysis beam. The maximum output power of the Nd:YAG laser was reduced to approximately 300 mJ per pulse, or 58.9 MW/cm^2. As with Johnson's experiment, the effective gain length was probably reduced due to the crossing angle of the photolysis beam. Given an effective gain length of at least 17 cm, however, the system was above threshold. Since lasing did not occur, the losses at the windows due to blackening and absorption by contaminants may have been excessive. The photolysis laser may not have been aimed for the best possible overlap with the laser mode volume, reducing the effective gain length below 17 cm.

The photolysis laser was set for 83 mJ per pulse and focused with a 1 m focal length lens at the center of the gain tube. The spot size of the beam was 2 mm diameter at each Brewster window, resulting in 330 MW/cm^2 of flux at the windows. Not surprisingly, the CaF_2 windows were damaged by the flux. The sapphire windows remained undamaged. However, black burn marks quickly appeared on the sapphire windows. Because of the 8 mrad crossing angle and focusing of the photolysis beam, overlap of the pumped region of gas and the laser mode volume was likely very low, resulting in a very low effective gain length.

V. Conclusions

Overview

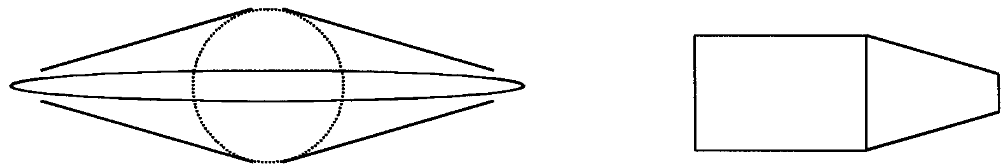
The nozzle apparatus used in this experiment did not succeed because the gain length was too short to provide the gain necessary to overcome cavity losses. IBr contamination on the inside surfaces of the nozzle windows could not be avoided and quickly increased cavity losses. Since the photolysis laser burned IBr onto the windows, several were also damaged as a direct result of contamination. Focusing the photolysis beam reduced the effective gain length so that the increased flux was not sufficient to produce lasing. Attempts to increase the pump energy above that required for lasing destroyed the Brewster's angle windows before lasing was achieved. To avoid similar problems in the future, an examination of the damage threshold of sapphire, BaF_2, and CaF_2 windows would be a worthwhile effort and would not be difficult.

Recommendations

In order to increase the probability of success in future CW IBr laser research, further research should be performed to characterize the populations of the different species involved in an IBr laser. Of particular interest should be IBr, Br and Br^*, as well as the quenching species I, I_2 and Br_2. Analysis of the populations of each chemical species will provide a better understanding of which mechanisms are most responsible for quenching a laser pulse. Harries and Meador state that heating should be detrimental to a solar-pumped IBr laser (4:200). Therefore, temperature rise in the lasing region of an IBr laser as a result of photo pumping should be investigated. Currently, rate coefficients for the quenching, recombination and exchange reactions involved in an IBr laser are only available for 300 °K. Temperature dependent rate coefficients should be determined to assist with modeling efforts. The same analysis should be performed with various buffer gases introduced. Zapata and DeYoung suggest that buffer gases extend laser pulse lengths by reducing temperature rise in the IBr gas (2:1692). However, a more detailed analysis may reveal that gaseous additives extend lasing by assisting or retarding some of the recombination or exchange reactions.

Once the mechanisms involved with lasing are clearly understood, the best possible nozzle for CW lasing can be designed. It may be necessary to allow nearly supersonic flow inside the nozzle. Therefore, an extensive understanding of compressible fluid flow should be applied to the nozzle design. To be useful in CW IBr laser experiments, testing of a nozzle design should reveal flow speed and temperature inside the lasing region as a function of back pressure and IBr vapor and buffer gas partial pressures.

If a nozzle similar to the current apparatus is to be used in the future, it should incorporate at least two design changes. The gain length, especially in flow mode, needs to be significantly longer, to decrease the threshold for lasing. Also, the walls of the chamber should be sloped at Brewster's angle for sapphire or BaF_2, so that damage threshold of the windows is not a limiting factor. To increase the gain length, a fitting will have to be designed for the vacuum pump, which gradually expands the cross-sectional area of the pump tube in the axis of the laser cavity. Simultaneously constricting the perpendicular axis would prevent an excessive increase in the pumping area, thereby minimizing loss in pump power due to the fitting.



(a) (b)

Figure 5.1. Proposed design for a new flow nozzle a) front view
b) side view

As calculations in Chapter III showed, the pressure differential required to reach 58.4 m/s in the current experiment was less than 1 Torr. In a nozzle 20 cm long, with a width of 0.3 cm, the pressure differential required to reach 58.4 m/s would be approximately 0.75 Torr. To ensure smooth flow in the lasing region, the windows can be placed so that gain occurs at the 3 mm throat of the nozzle.

Summary

The experiment was not as successful as was hoped. The threshold for lasing proved unattainable as a result of the equipment used. The failures of the CaF_2 windows and of the photolysis laser were unforeseen obstacles. Though CW lasing was not achieved, several roadblocks were identified and suggestions made to improve further research.

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An apparatus to generate continuous wave (CW) lasing at 2.714 mm by Br(2P1/2) atoms produced from photodissociation of IBr was designed, constructed and tested. A frequency doubled Nd:YAG laser firing 8 ns, 850 mJ pulses at 532 nm was used to photodissociate static IBr vapor inside a flow nozzle. The CaF2 windows on either side of the nozzle proved to have a damage threshold below the threshold for lasing. Pulsed lasing in static mode was not observed. Therefore, CW lasing in flow mode, using an Ar+ laser at 488 nm, could not be investigated.

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