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Experimental set-up for Heavy-Ion-Beam Pumped Excimer Laser Experiment

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The use of heavy-ion beams for pumping gas-lasers had first been demonstrated in 1983 by pumping an infrared He-Ar laser with a 100 MeV ^{32}S beam from the Munich Tandem van de Graaff accelerator [1]. Heavy-ion beam induced amplified spontaneous emission was observed at GSI for the xenon excimer at 172 nm [2]. Various schemes for ion beam pumped lasers have been studied spectroscopically [3–5]. The improved beam intensity and beam quality of the heavy ion synchrotron SIS-18 at GSI, Darmstadt open a possibility to realize different experimental programs. For the first experiment with the heavy-ion-beam pumped excimer laser well known KrF^* excimer laser line at a wavelength of 248 nm has been selected, because this wavelength is still long enough to propagate in air without attenuation. The next step to extend the laser experiments into the VUV range of the spectrum λ<200 nm) to the excimer laser transitions of the pure rare gases between 80 and 170 nm (Ne_2^* through Xe_2^*). In the course of our studies concerning ion beam pumped lasers the interest has shifted from potential applications of the intense VUV laser light to the fact that observing laser effect provides a very sensitive method to study the gas kinetics and plasma conditions in the target.

A fundamental aspect of laser experiments is to obtain enough pumping power density in a volume which is large enough, at least in one dimension, so that the optical gain times the length reaches a minimum value. The pumping power density which is required to reach laser threshold it can be expected that the experiments will reach an upper limit of pumping power for which laser effect can be observed. This is due to the fact that the excimer molecules, the species in the upper laser level, will no longer form at high temperature conditions in the investigated materials. Temperatures up to $\sim$5000 K are expected which corresponds to an average energy of

0.5 eV/atom. This has to be compared with the binding energy of the excimer molecules which is on the order of 1 eV. Gas temperatures, densities of excited species, and plasma parameters such as electron density and electron temperature in heavy ion beam induced plasmas shall be derived from the beam parameters for which laser effect will be observed.

The laser setup consisted of a 1.2 m long stainless steel tube of 30 mm diameter placed about 2 m behind an exit foil of the HHT beamline (Figure 1). A pulsed beam of ^{238}U ions with a particle energy of 250 MeV/u and $\sim$110 ns pulse duration (FWHM) was used for pumping. The projectiles traversed 2 m of air, a 600 μm thick scintillator, a stainless steel entrance foil, a 3 mm thick glass mirror substrate, and were then stopped in the laser gas mixture. Single shot pulses of up to 2.5·10^9 particles/pulse were focused into the laser cell. The optical resonator was formed by a flat, Al-coated mirror near the beam entrance and a second dielectrically coated, highly reflective mirror with 3 m radius of curvature at a distance of about 1 m (Figure 2).

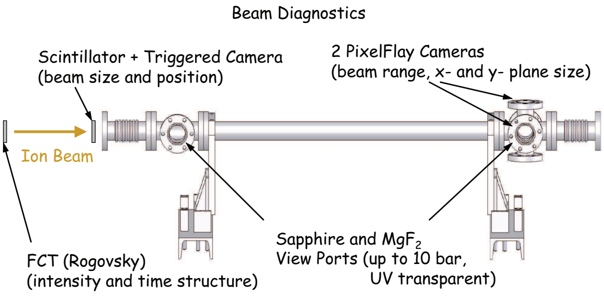

Figure 1: Laser stainless steel tube and heavy ion beam diagnostic.

This end mirror was also used as a window for the cell to decouple the light from the resonator. A laser gas mixture of approximately 50% Ar and 50% Kr with 0.5% F_2 admixture was used as the laser medium. A constant gas flow was maintained to avoid F_2 depletion due to chemical reactions. Two fast UV enhanced photodiodes with 248 nm filters and two small monochromators with fiber optics input were used for laser diagnostics.

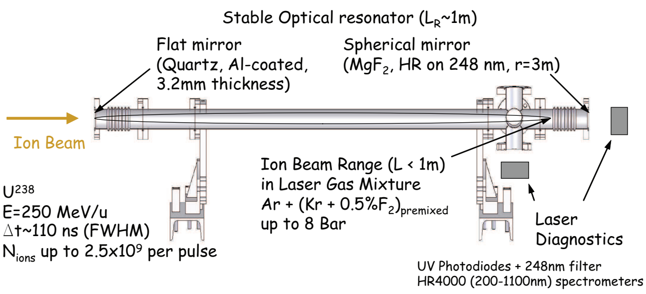

Figure 2: Stable optical resonator and laser light diagnostics.

SRIM simulation [6] for energy loss of ^{238}U ion beam in laser cavity was done to optimize geometry of the experiment and pumping ion beam energy. About 200 MeV/u ion beam loss before laser cavity on: 2 m air gap between entrance of the laser tube and output of the beam line; 600 μm scintillator placed on the entrance of the laser tube; 50 μm stainless entrance pressure resist window; 3.2 mm quartz laser cavity mirror.

In order to understand the expansion of the beam heated laser gas volume, numerical simulations on hydrodynamic response of the beam-heated gas have been carried out. In the simulations, the VarJet code [7] has been employed. This code is capable of solving 2D full time-dependent Navier-Stokes equations for multicomponent gas mixtures, including viscosity, heat conductivity and diffusion effects. The initial and boundary conditions were taken as in the experiment whereas the beam-induced heating of the gas was calculated using the SRIM stopping power data and neglecting radiative energy dissipation. The following input data for ion beam related to the experimental condition were used for a numerical simulations: number particles $N_i=2\cdot10^9$ ions/pulse; ion beam shape: normal distribution with σ=0.51mm; gas mixture 50%Ar+50%Kr, initial pressure 2 bar.

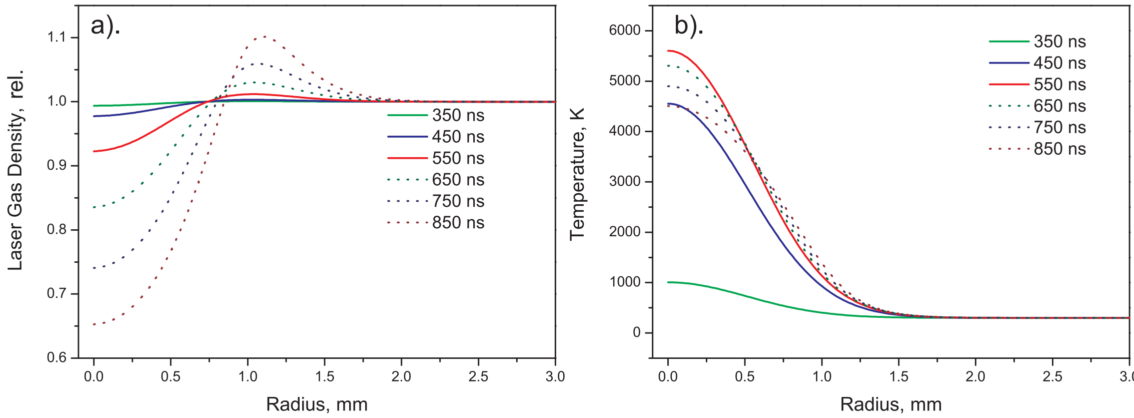

Figure 3: Laser gas density a). and temperature b). simulation (ion beam come at 300 ns).

The simulation results for laser gas hydrodynamic response during and after ion beam irradiation is shown in Figure 3. Due to expansion of the beam heated gas volume the target density in this region reduced on 5-7% in time of the ion beam duration and on the 300 ns after ion beam the gas density on the ion beam axis drop down about 35%. The laser gas temperature reached maximum at the end of the pumped ion beam pulse and on the 300 ns after ion beam stay about 5000÷4500 K.

Experimental set-up for demonstration of a heavy-ion-beam pumped excimer laser was assembled at the HHT target area of the heavy ion synchrotron SIS-18. The layout of the experimental set-up with heavy ion beam diagnostics, scheme of the optical resonator and laser light diagnostics are shown on Figure 1 and Figure 2. The ion beam was first steered and focused into the laser cell with about 10^8 particles/pulse. Spontaneous emission near the end of the cell was observed with cameras. Laser gas pressure in cell was reduced to match for ion range the length of the cell. For a gas pressure of 1.6 bar the range of the ions matched the length of the cell. When the beam intensity was raised to about $2\cdot10^9$ particles/pulse laser effect was immediately observed by a strong appearance of the 248 nm line in the spectrum emitted along the laser axis. Laser threshold was reached with $1.25\cdot10^9$ particles/pulse for this specific setup.

The time structure of the emission of spontaneous as well as laser light at 248 nm was recorded with the photodiodes. The time structure contains important information about the gas kinetics, development of the gas temperature and plasma parameters. The half-width of spontaneous emission was 190 ns and the laser pulse duration ranged from 59 to 84 ns for pumping intensities between 1.4 and $2.5 \cdot 10^9$ particles/pulse. A first indication of spectral narrowing was also observed by comparing spectra of spontaneous and laser emission, respectively, recorded with one the low resolution spectrometers. Time and spectral narrowing of laser light shown on Figure 4.

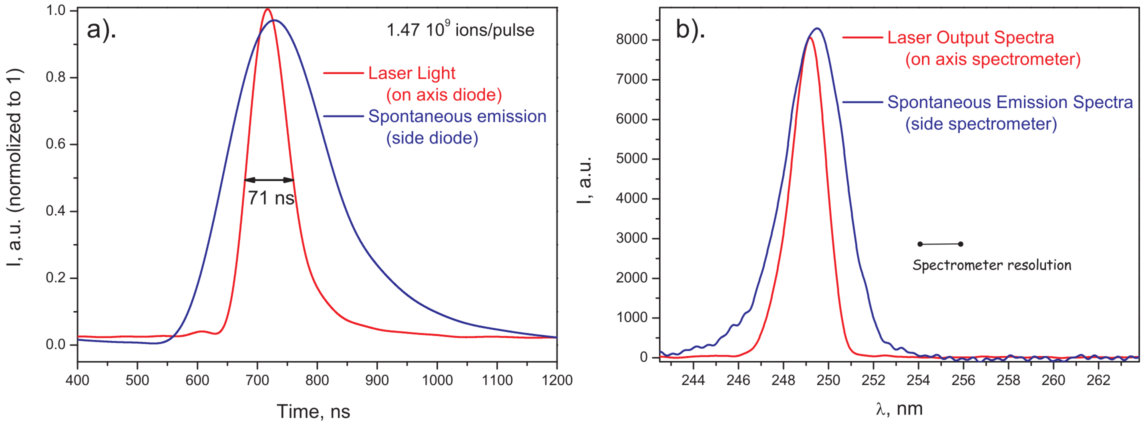

Figure 4: a). Time structure of the spontaneous emission and the laser pulse. b). Spectra of the spontaneous and laser emission, respectively, recorded with one the low resolution spectrometer.

The successful test experiment with KrF* excimer laser has demonstrated that the pumping power level and beam quality available from GSI, Darmstadt accelerator SIS-18 is now sufficient to perform laser experiments and it is planned to extend the laser experiments into the VUV range of the spectrum (λ<200 nm) to the excimer laser transitions of the pure rare gases.

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