Recombination Laser Schemes in Combined Electrical and Heavy Ion Beam Induced Plasmas

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Heavy ion beam pumped recombination laser schemes are studied by sending an ion beam pulse into a 300 mbar ($n_{He} = 10^{19} cm^{-3}$) Helium gas target.

The gas is partially ionized by an electrical discharge providing a high density of free electrons required for recombination and subsquent collisional deexcitation of multiply charged target atoms which are effectively produced by the heavy ion collisions. A special discharge forming a dense, homogeneous streamer distribution with electron densities above $10^{14} cm^{-3}$ between two knife edge electrodes has been developed. The discharge is on for only 20 ns followed by rapid cooling of the electrons by collisions with He- atoms. Around 200 ns after the discharge the electron temperature is low enough for three- body recombination with He^+ ions to set in. The plasma parameters n_e and T_e as calculated using a numerical model are shown in fig. 1.

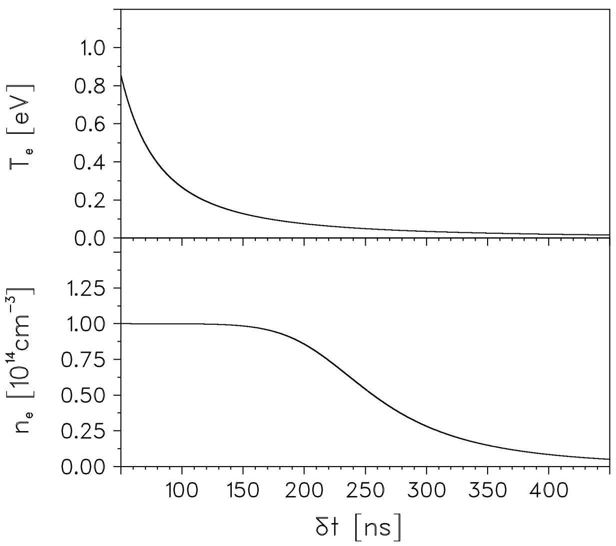

Fig. 1: Time evolution of electron temperatur T_e and electron density n_e after the termination of the electron producing streamer mechanism in the discharge.

Pulses of 100 MeV ^{32}S ions with 2 ns duration were sent into the plasma target at various delay times with respect to the electrical discharge. Highly excited target species such as He^{2+} and He^{+*} (e.g. in the $n = 3$ level) ions are produced by heavy ion collisions. A net cross section for producing He^{+*} $(n = 3)$ of $10^{-19} cm^2$ has been measured. Recombination of $He^{2+}(n_{He^{2+}} \approx 1.6 \times 10^{10} cm^{-3})$ and collisional deexcitation of $He^{+*}(n \geq 4)(n_{He^{+*}(n=4)} \approx 3 \times 10^7 cm^{-3})$ ions with free electrons in the plasma ($n_e \approx 10^{14} cm^{-3}$) were studied by measuring the light output on the $n = 3$ to $n = 2$ transition in He^{+*} at a wavelength of 164 nm.

Modeling of recombination mechanisms is e.g. described in ref. [1], [2], and [3] and the experimental setup used in ref. [4]. Light intensity as measured without igniting the discharge is used as a reference. An increase in light output on the 164 nm line due to the interaction of free electrons with the heavy ion beam produced species in the discharge plasma as predicted by the modeling is observed with a maximum effect of a factor 1.4 , 200 ns after the discharge (fig. 2).

The time dependence of light enhancement reflects the time evolution of the plasma parameters in the plasma target. Solving the rate equations for He^{+*} for various plasma parameters shows that the data can be interpreted predominantly by two competing processes: Electron collisional deexcitation and spontaneous emission. The ratio of these processes is also essential for establishing an inversion in recombination laser schemes [3]. A sufficiently high electron density n_e and low electron temperature T_e leads to a high electron collisional deexcitation rate ($\sim \frac{n_e}{\sqrt{T_e}}$) of heavy ion beam induced He^{+*}-ions with $n \geq 4$ down to the $n = 3$ level. This leads to a population enhancement of the He^{+*} $(n = 3)$ level. The efficiency of this mechanism can be estimated by comparing the electron collisional deexcitation rate $R_{4,3}$ and the rate of spontaneous emission $A_{4,3}$ from levels $n = 4 \rightarrow n = 3$. The ratio $R_{4,3}/A_{4,3}$ is shown in fig. 2. It is calculated using the data shown in fig. 1.

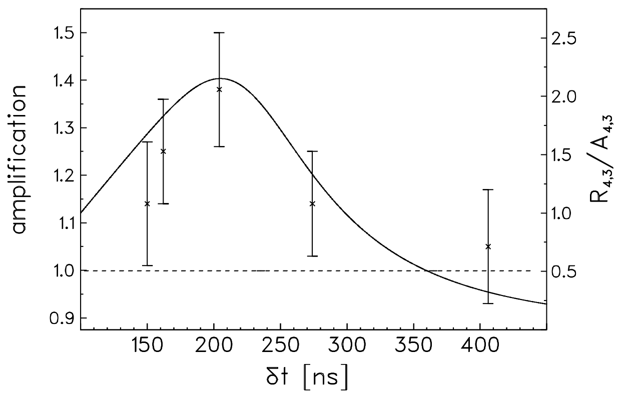

Fig. 2: Enhancement in light output on the 164 nm line ($n = 3 \rightarrow n = 2$) of He^{+*} ions excited by a heavy ion beam interacting with a He gas discharge plasma at a time δt after termination of the discharge. The solid line shows the ratio of the electron collisional deexcitation rate $R_{4,3}$ and the rate of spontaneous emission $A_{4,3}$.

References

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