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BUDKER INSTITUTE OF NUCLEAR PHYSICS

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FEASIBILITY OF COHERENT VUV SOURCE BASED ON BEAM-PLASMA SYSTEM

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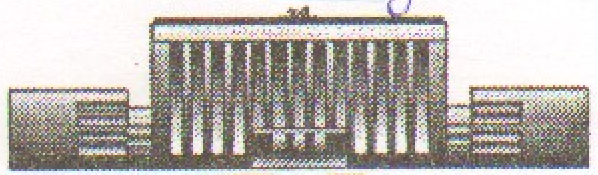

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Feasibility of Coherent VUV Source Based on Beam-Plasma System

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Abstract

A new approach to VUV generation is discussed. A bunch of multi-Z plasma with $\sim 10^{17}$ cm^{-3} density and ~50 eV temperature is used as an active medium. A high-power stream of keV-range electrons from 10^{15} cm^{-3} plasma, heated by a relativistic electron beam, serves as a source for excitation this bunch. In this case specific energy deposition per atom of laser medium is much higher than in schemes with direct pumping by an electron beam. Prospects of achievement of inverse population in the experiments at the GOL-3-II facility are considered.

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1. Introduction

Plasma-based systems are often used as sources of short-wavelength emission, including coherent one. A number of realized systems with inverse population of levels in VUV and soft X-ray regions are known (see, e.g., [1]). A problem of VUV generation is concerned with availability of effective optical elements and with necessity for effective input of power into an active medium.

In this paper a new approach to VUV generation is discussed. In this scheme a high-power electron stream from a plasma, heated by a relativistic electron beam, serves as a source for excitation of laser media. A plasma cloud with 10^{16}-10^{17} cm^{-3} density and 10-50 eV temperature is used as an active medium. Prospects of achievement of population inversion in the experiments at the GOL-3-II facility [2] are considered.

2. Beam-Plasma Interaction

A beam-plasma systems are widely known mainly due to studies of basic plasma physics. With the development of pulsed power technology and generators of relativistic electron beams such systems became employed also for fast plasma heating in solenoids. During the injection of a relativistic electron beam into a plasma, a resonant Langmuir oscillations are excited in this plasma under certain conditions. If growth rate Γ of a two-stream instability exceeds electron-ion collision rate ν_{ei}, an effective beam relaxation on a distance much less than free path length of relativistic electron in such a plasma is possible. Several experimental teams have achieved collective loss of beam energy up to 30-40% on a few meters length. Typical experimental parameters are: $n_e \sim 10^{15}$ cm^{-3}, beam current density 1-10 kA/cm^2, beam duration 0,1-10 μs. Major fraction of energy lost by the beam is deposited to plasma electrons, mainly to superthermal electrons with typical energy above several keV.

A condition $\Gamma > \nu_{ei}$ is necessary for development of two-stream instability, it limits upper plasma density of $\sim 3 \cdot 10^{15}$ cm^{-3} as a practical restriction for the electron beams with specified current density. To raise the plasma density accessible for this heating technique, a so-called 'two-stage heating scheme' is developed. In this scheme a long column of a background plasma with low acceptable density is heated by the beam due to collective interaction. Then hot electrons of this plasma transfer their energy to adjacent short region of a dense plasma by binary collisions.

3. Lasing Schemes

Inverse population can be achieved directly by electron impact during the interaction of electron beams with gases or by three-body recombination during the plasma decay. A large number of works on lasing is known with pumping by electron beams of 0,1-1 MeV range. Feature of our approach is that the column of low density plasma *de-facto* serves as transformer of flux of 1 MeV electrons of the initial electron beam to flux of hot plasma electrons with less energy but essentially higher current density (even with interaction efficiency taken into account). In this case specific energy deposition per atom of laser media is much higher than in schemes with direct pumping by an electron beam. This enables to reach higher temperature and ionization degree of an active medium, and gives prospects for achievement generation in shorter wavelength at comparable parameters of the electron beam.

Ions with population high enough in a relatively wide interval of plasma temperature are chosen as primary candidates for VUV generation (this is essential for pulsed plasma which temperature changes over time and space). A temperature range of 20-50 eV is considered as suitable and typical for experiments on the GOL-3 facility (see [3]). Preliminary calculations for $n_e = 10^{17}$ cm^{-3} plasma under some assumptions give the following values [4].

Element	*Mg* III	*Al* IV	*Si* V	*C* IV	*N* V
Pumping	collisional			recombinative	
Ion	*Ne*-like			*Li*-like	
λ, nm	155.1	148.1	87.4	253.0	162.0
Gain, cm^{-1}	$4.9\cdot10^{-1}$	$2.3\cdot10^{-1}$	$9.4\cdot10^{-2}$	$5\cdot10^{-3}$	$6.6\cdot10^{-4}$
Intensity, W/cm^3	$1.2\cdot10^{5}$	$6.8\cdot10^{4}$	$2.2\cdot10^{5}$	$1.7\cdot10^{2}$	$1.3\cdot10^{2}$

4. Device and Experiment

Experiments are carried out at the GOL-3-II facility [2] - Fig.1. It comprises a generator of an electron beam; 12 m length plasma chamber inside a solenoid with 5 T magnetic field and with 10 T in end mirrors; 15 MJ capacitive storage for feeding the solenoid; systems of control and diagnostics. The electron beam has energy ~1 MeV, 8 μs pulse duration and energy content up to 200 kJ. At the device input a special short mirror trap with *R*~7 is placed for experiments with VUV-emitting multi-charged plasma.

Preliminary experiments were carried out using uniform magnetic field on the GOL-3-I facility (see [4]). A gas with predetermined element ratio was puffed by pulsed valves so that dense cloud length can be set from 0.5 to 3 m prior to beam injection. Dense cloud of 5% N_2 + 95% H_2 gas mixture was injected into the device at 5 m distance from the beam input. Depending on the regime of the experiment the density of the cloud in its central point was from (5-6)$\cdot10^{14}$ cm^{-3} without gas puffing and up to $8\cdot10^{15}$ cm^{-3} with the cloud. Measured plasma temperature was 10-50 eV. Power of flash of VUV emission with $\lambda < 100$ nm exceeds 10 kW/cm^3, that gives total power, radiated by the cloud, $P > 10$ MW and total energy of $Q \sim 100$ J (for initial energy content of the beam ~ 40 kJ).

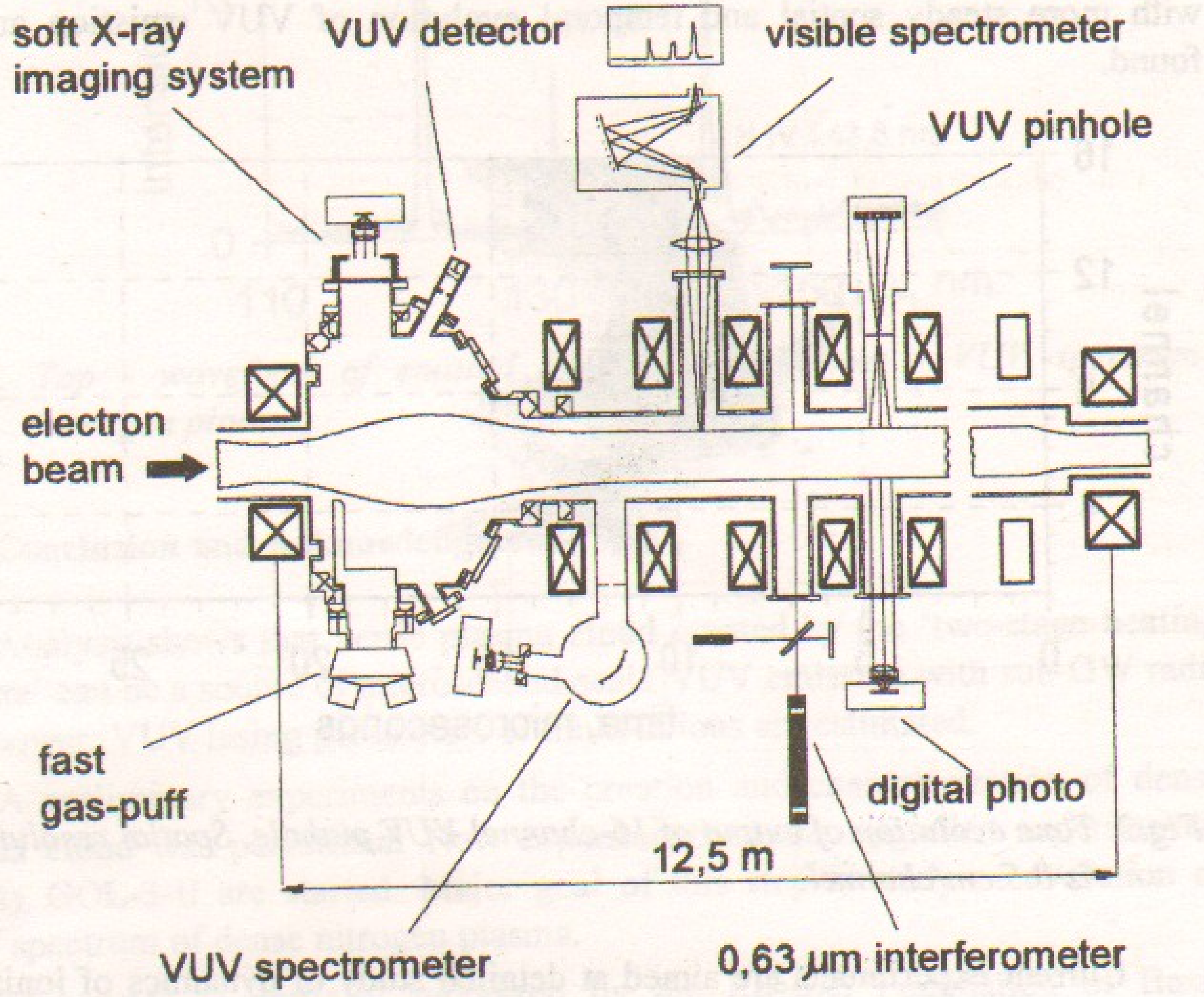

Fig.1 Layout of the experiment.

The experiments [4] showed two main issues of the proposed scheme. First of all, energy have being deposited into dense cloud are not sufficient to heat high-Z plasma to needed temperature. Second, in a straight solenoid the input energy mainly transforms into the longitudinal expansion of the cloud with ion energy $mv_{\parallel}^2/2 >> T_i$.

New facility GOL-3-II enables to overcome these restrictions because it has tripled energy content of the electron beam and increased length of the background plasma column [2]. Experiments on VUV generation are supposed to be done in special short trap with mirror ratio ~5 for further increase in specific parameters of the dense cloud and in its lifetime. Figure 2 shows evolution of output of 16-channel VUV pinhole (aluminum photocathodes) in the experiment with D_2 puffing. Duration of the beam was ~5 μs for this shot. Maximum of emitted VUV power occurs after the heating end. Localized bright spots with short lifetime are observed. The spots might indicate fast change in ionization state of plasma impurities or presence of shock waves in the plasma. Regimes with more steady spatial and temporal evolution of VUV emission are also found.

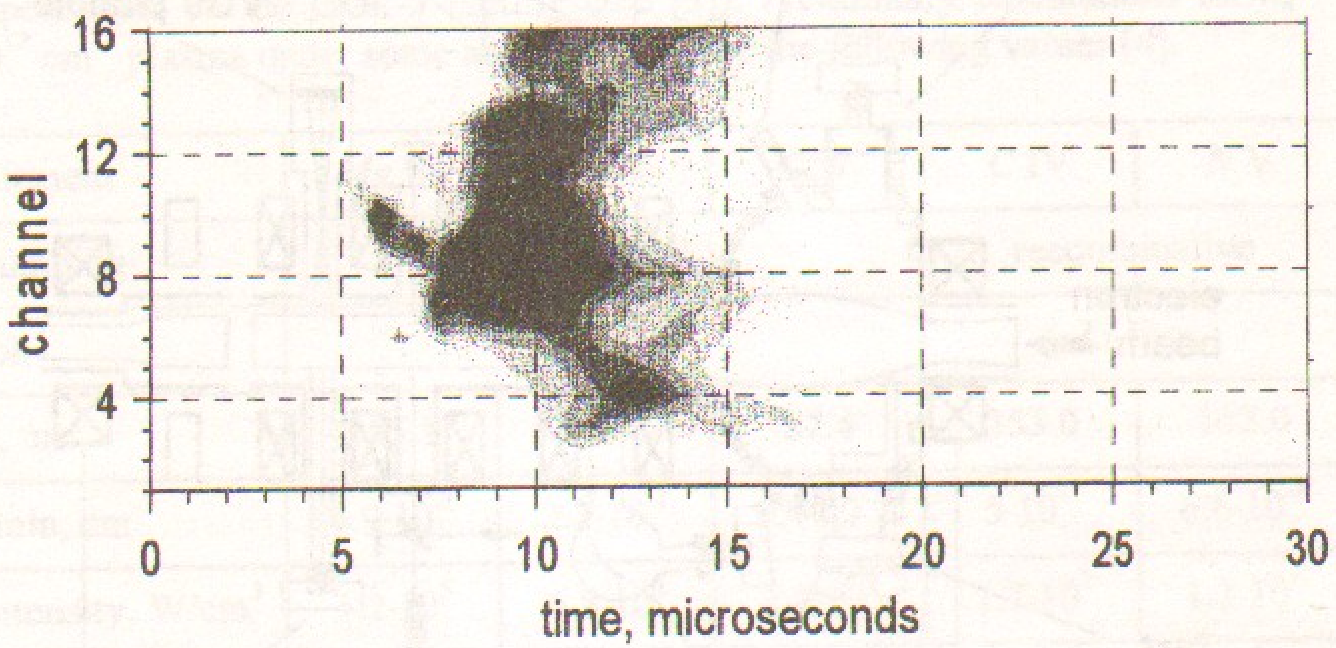

Fig.2. Time evolution of output of 16-channel VUV pinhole. Spatial resolution is 0.5 cm/channel.

Current experiments are aimed at detailed study of dynamics of ionization states of a non-hydrogen plasma. Main diagnostics are soft X-ray imaging system, VUV spectrograph (both are with 1 μs frame and digital readout) and 16-channel VUV pinhole detector. Typical VUV emission spectrum of dense nitrogen plasma is shown in Fig.3. Optimization of parameters of the dense plasma continues.

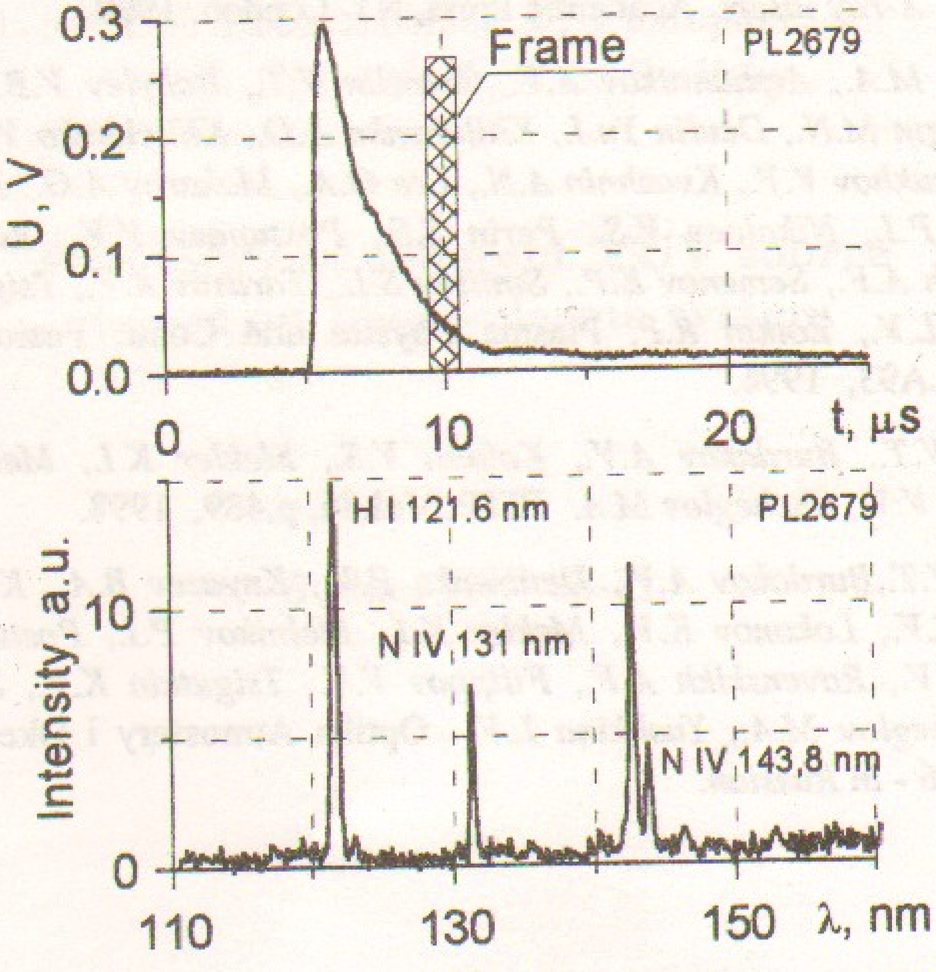

Fig.3. Top - waveform of emitted VUV power, bottom - VUV spectrum (nitrogen plasma).

5. Conclusion and Acknowledgments

Analysis shows that dense plasma cloud created by the 'two-stage heating scheme' can be a source of microsecond-scale VUV emission with sub-GW radiated power. VUV lasing parameters of multi-Z ions are estimated.

A preliminary experiments on the creation and characterization of dense plasma cloud was performed. New experiments at the upgraded experimental facility GOL-3-II are started. Major goal of this step is study of evolution of VUV spectrum of dense nitrogen plasma.

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