Development of VUV Light Sources and Lasers ◇

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Ultraviolet light sources which use low energy electron beam excitation of dense gases as the light producing mechanism are developed in a collaboration of two companies, the GSF-Forschungszentrum für Umwelt und Gesundheit and TU-München. The project is funded by the Bayerische Forschungsstiftung. The different tasks in this project which have been described in detail in the previous annual report [1] were intensively pursued in 2004. Briefly, an electron gun is combined with a gas cell. The electron gun is a sealed off device providing a 15 keV electron beam. This beam is sent through a thin (300 nm) ceramic membrane (SiN_x) into gases with pressures up to 5 bar. Typical dimensions of the membrane are 0.7 by 0.7 mm^2 or 0.7 by 40 mm^2, respectively. About 10% of the beam power is deposited in the membrane and the rest is used for collisional excitation of the species in the gas cell. Radiative transitions following this excitation are used as the light emitting process in the incoherent and coherent light sources.

The scientific task is to find and optimize gas fillings and gas mixtures which lead to efficient light emission with appropriate characteristics such as wavelength and bandwidth. Devices based on the technique described above can be operated from pulsed mode to fully continuous. Power levels which can be achieved are determined by the thermal stability of the membrane. About 10 μA can be tolerated in dc mode and more than 1 A beam current can be sent through the 0.5mm^2 membranes in pulses of several 100ns duration. For the 0.7 by 40 mm^2 membranes these values increase according to the increase in membrane area. The pulsed high current mode can be used to develop table-top electron beam pumped lasers.

Major technical achievements in 2004 were the completion and testing of a computer controlled power supply, a more than 1000 h lifetime test of a membrane with 5μA beam current followed by a 500 h test with 10μA, the design and test of a portable gas purifier, and a short test of a 585nm visible laser as a model system for shorter wavelength lasers. Sealed off electron guns are still under development at THALES Electron Devices. First prototype VUV light sources were successsfully tested in mass spectrometers at the GSF research institute, in particular with a newly designed quadrupole type mass spectrometer [2]. Optimization of an Ar-H_2O lamp emitting at 310 nm and measurements of self-quenching- and water-vapor quenching rates for the excited molecular state C of nitrogen [3] were performed at TUM. These studies are described in separate contributions to this annual report. The test of a He-Ne-Ar laser as a model system for very compact electron beam pumped lasers is described below.

A comercially available high current electron gun (Litton Corp.) which was used in ref. [4] to study the electron beam induced temperature increase of pure rare gases was now equipped with a specially designed flange for mounting the entrance membrane for the electron beam. The laser cell and mirror mounts were incorporated in this flange. A schematic drawing of the device is shown in Fig. 1.

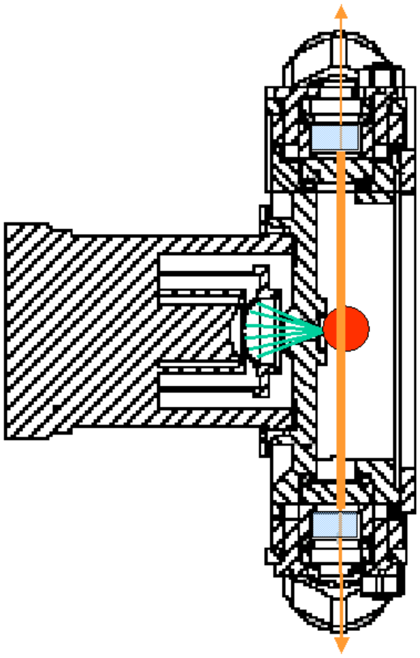

Fig. 1: Schematic drawing of the electron beam pumped laser setup. The 12keV beam is produced in the Pierce type electron gun (left) and sent through a 300nm thick SiN_x membrane into the laser gas. The laser axis has a vertical orientation in this drawing and is defined by the two laser mirrors.

The pierce type electron gun can provide beam currents of more than 1 A. A stable optical cavity was formed by two spherical mirrors of 0.5 m radius of curvature and ≈99% reflectivity at a wavelength of 585 nm placed at a distance of 6 cm. The laser cell was filled with a gas mixture of 1000 mbar He, 30 mbar Ne, and 20 mbar Ar and the electron beam excited volume was used as the laser medium as indicated in Fig. 1. The gain medium is in this case a roughly spherical volume of only 10 mm diameter.

Laser effect in dense He-Ne mixtures was first described by Basov et al. [5]. Heavy ion beam pumping of this laser system had been demonstrated at the Munich Tandem accelerator [6]. The laser line is an optical transition ($3p'[1/2]_0 \rightarrow 3s'[1/2]_1^o$) in NeI (neutral neon atoms). The pumping scheme is rather complex and of the type of a recombination laser. Dissociative recombination of $HeNe^+$ ions is believed to be the main process for populating the upper laser level. An admixture of Ar (or Xe which can be used alternatively) allows to maintain quasi continuous population inversion by predominantly depopulating the lower laser level collisionally. This mechanism had already been exploited in low pressure He-Ne lasers. Here the sys-

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tem was pumped by a typically 350 mA electron beam with 100 ns pulse duration (4200 W, 0.42 mJ) leading to a power and energy deposition on the order of $10 \mathrm{kW/cm^3}$ and $1 \mathrm{mJ/cm^3}$, respectively. The laser was operated at a 2 Hz repetition rate.

Laser effect was demonstrated by measuring emission spectra from the device along the laser axis and perpendicular to the laser axis. The results are shown in Fig.2. It can clearly be seen that only the 585 nm line appears in the spectrum emitted on the laser axis whereas the typical multi-line emission of neon appears in the spontaneous light emission perpendicular to the laser axis.

Laser effect was of course very sensitive to mirror alignment. Note, however, that the almost spherical gain medium is rather insensitive with respect to the exact orientation of the laser axis defined by the orientation of the mirror surfaces.

Another clear proof of laser effect is the threshold behaviour of laser output with pumping power as shown in Fig. 3.

Laser effect has the interesting time structure shown in Fig. 4.

Pumping power is deposited in the gas only during the first 100 ns. Spontaneous emission starts instantaneously whereas the laser output shows a delay of 200 ns and then lasts until roughly 1μs after the onset of the pumping pulse. The delay in the laser output of a recombination type laser can be attributed to the gas kinetic processes in particular the cooling phase of the electrons since a high recombination rate is reached only when this cooling phase is over.

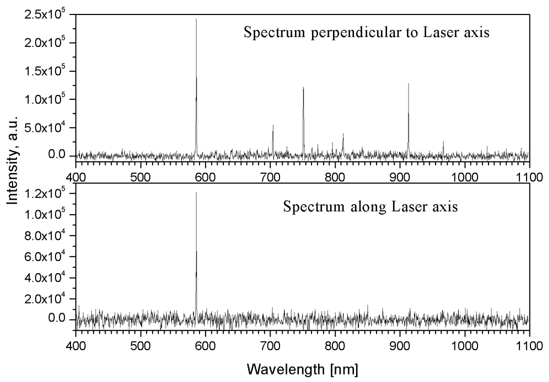

Fig. 2: Spontaneous emission from the laser device (top) and 585nm laser light emitted on the axis (bottom) for comparison

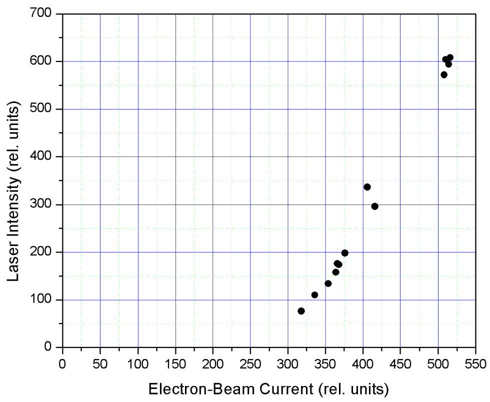

Fig. 3: Laser output vs. electron beam. The threshold behaviour is a clear indication of laser effect.

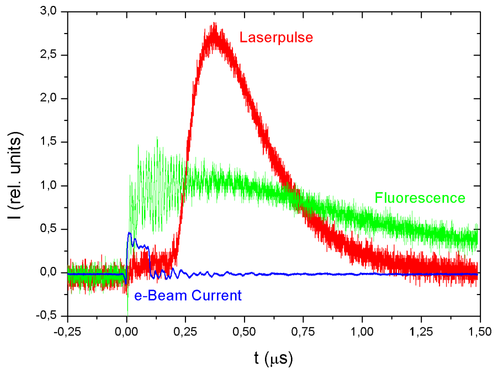

Fig. 4: Time structure of the 585nm He-Ne-Ar laser. Pumping power is provided by the electron beam for 100ns. Spontaneous emission sets in as soon as the pumping starts. Laser effect is delayed due to gas kinetic processes and mechanisms discussed in the text.

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