# Development of Novel Ultraviolet Light Sources ◇

A.Morozov , A.Ulrich , R.Krücken , A.Görtler [a], A.Hohla [a], J.Piel [a], J.Wieser [a], G.Kornfeld [b], R.Steinhübl [b], F.Mühlberger [c], and R.Zimmermann [c]
[a] TuiLaser AG, Industriestr. 15, 82110 Germering,
[b] THALES Electron Devices, Söflingerstr. 100, 89077 Ulm,
[c] GSF, Ingolstädter Landstr. 1, 85746 Neuherberg

Electron beam induced light emission is investigated in order to develop ultraviolet light sources which may eventually be commercially available. Extremely thin ceramic membranes are used as the entrance window for the electrons. This allows rather low energy electrons with energies between 10 and 20 keV to be used. Based on earlier pioneering work [1]- [5] a group of two companies, TuiLaser and THALES Electron Devices (TED), together with the GSF research center Neuherberg, and TU München have started a common project to develop this concept. Both electron beam pumped UV incoherent light sources and UV lasers will be realized and their practical application will be demonstrated. The project is funded by Bayerische Forschungsstiftung.

The first goal in this project is to develop incoherent excimer light sources. Excimer molecules are electronically excited dimers which decay radiatively to a repulsive ground state. Very high conversion efficiencies of electron beam power into ultraviolet light of more than 30% had been observed in the case of rare gas excimers [1]. Other efficient light emitting systems are based on energy transfer processes from rare gas molecules to other species. Hydrogen, which is dissociated in collisions with $Ne_2^*$ with one Hydrogen atom in the n=2 state, emits with more than 10% efficiency selectively on the Lyman-alpha line [2]. Argon nitrogen mixtures emit strongly on the C-B band in the 300 to 400nm wavelength range [6]. Other ultraviolet light emitting species are the rare gas halides (ArF, KrF, etc.). They can be effectively pumped with electron beams [5] and it is planned to use these systems to develop compact electron beam pumped lasers.

The basic technology has been described in more detail in previous annual reports. Briefly, 300 nm thin silicon nitride (or silicon nitride-silicon oxide double layer) films are deposited on a silicon wafer. Free standing membranes on frames consisting of sections of the silicon wafer are produced by etching techniques. Typical dimensions of membranes used in our project are 0.7 by 0.7 mm$^2$ on a 5 by 5 mm$^2$ piece of the wafer or 0.7 by 40 mm$^2$ membranes on a 10 by 50 mm$^2$ piece of the wafer. The fraction of the beam power which can be transmitted through the ceramic membranes is shown versus electron energy in Fig. 1. A Monte Carlo program [7] was used for modelling the energy loss and angular scattering of the electrons in the membrane. These numerical simulations which are now being used allow a much better quantitative description of the devices than the estimates based on tabulated electron energy loss tables, presented in earlier publications.

The limiting factor of the technology described here is the stability of the membrane. It has to withstand pressure differentials up to several atmospheres at temperatures on the order of 1000°C. Heat conduction along the membrane surface can be estimated to be only a minor contribution to removing the power deposited in the membrane by the electron beam. In the year 2003 we have found an additional way for cooling the membrane by adding a thin black layer on the vacuum side of the membrane which allows radiative cooling. Note, that the thin silicon nitride membrane, alone, is optically transparent and has therefore only a low emissivity. Using the experience of the MLL laboratory for thin films [8] we have added a thin, black carbon layer to the membrane and observed an improved thermal stability which may allow an up to 5× increase of the power which can be transmitted through the membranes. Besides the improved net cooling effect, the $T^4$ dependence of radiative cooling has a smoothening effect spacially as well as temporaly. Hot spots on the membrane as well as short overheating periods are damped by the the power-to-the-4th law of radiative cooling.

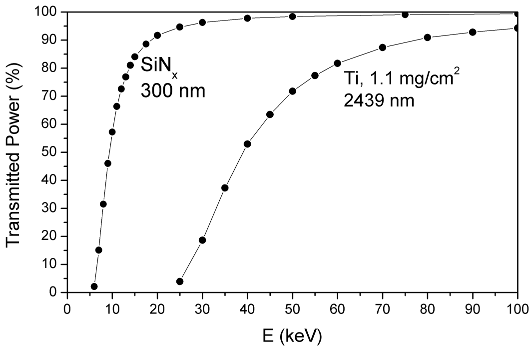


Fig. 1: Numerical simulations [7] of the percentage of electron beam power transmitted through a 300nm $SiN_x$ and a 1.1 mg/cm$^2$ Ti-foil, respectively is shown vs. energy of the incident electrons.

Several tasks have to be accomplished in the project. A compact electron gun has to be developed and the vacuum in this gun has to be separated from the gas filling in the lamp. The gas cell has to be designed and combined with appropriate vacuum ultraviolet optics for extracting the light from the lamp. Gas cleaning devices for sealed-off, portable operation have to be included. A power supply has to be built which allows fail-safe operation in continuous as well as pulsed mode of operation and meets the specifications for a commercial product. Spectral characterisitcs and the absolute light output of the UV/VUV lamps has to be specified, and finally, the lamps will be used for photoionization in mass spectrometers by the GSF.

A special electron gun (named ELG 20) for the operation

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of an incoherent point light source has been designed and built by THALES Electron Devices (TED). It is only 5cm long and consists of a hot cathode and three accelerating and focusing grids. It will allow beam currents up to 20mA. It is completely seald off and the cathode material acts as a getter pump maintaining an ultra-high vacuum in the electron gun volume. A soldering technique has been developed by TED for leak-tight mounting of the membrane (held on the silicon wafer material) on metal flanges. The first prototypes of the electron guns have been manufactured and the beam parameters will now be tested. The goal is to achieve a homogeneous irradiation of the 0.7 by 0.7 mm$^2$ membrane which is mounted on a CF-16 flange.

The gas cell to be connected to that CF-16 flange interface has been developed by TuiLaser in close collaboration with the TUM group. It provides a 3 cm$^3$ gas volume allowing an energy deposition depth of the electron beam of up to 5 mm. Gas can be circulated through the cell for cleaning the walls prior to filling. Limited by the maximum pressure differential of the membrane, it can be filled with gases up to 5 bar pressure. For portable operation the gas in- and outlet can be closed by clamping two copper pipes. To provide continuous cleaning of rare gases in the sealed off device a small gas purifier using a nonevaporable getter as the gas cleaning material has been developed. A 20mm diameter $MgF_2$ plate is used as the output window for the ultraviolet light. The geometry of the gas cell allows a large D/f value of 0.5 to be used for the optical output coupling.


Fig. 2: Photograph of the first industrial prototype of a 121 nm Ne-$H_2$ lamp, described above, together with a regular data-CD for size comparison

A fully electronically controlled power supply unit has been developed for running the light source. It provides an acceleration voltage up to 17 kV for the electron beam. The beam current is measured via a shunt resistor and electronically stabilized within $\pm$100 nA. Beam currents up to 50 $\mu$A (dc) can be used. Pulsed operation with pulse duration ranging from 100 ns to 20 $\mu$s and up to 10 kHz repetition rate can be used with peak currents up to 20mA. The average beam current is automatically limited to 30$\mu$A by the software in the power supply to avoid overheating and breaking of the silicon nitride membrane. The power supply is presently being programmed with the parameter settings necessary for reliable operation of the light sources. Housings for both the lamp and the power supply have been designed. A picture of the UV/VUV lamp (called "e-lux", followed by the main emitted wavelength) in its housing is shown in Fig. 2.

Since several potential customers for UV lamps are interested in light sources radiating on the wavelength emitted by the rare gas halide excimer lasers, ArF at 193nm in particular, test runs with the lamp operated on this wavelength have been performed. An emission spectrum is shown in Fig. 3.

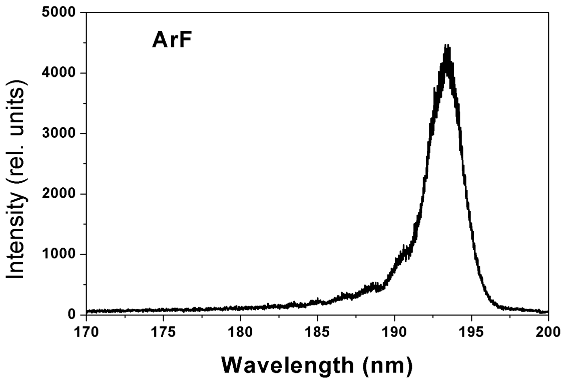


Fig. 3: ArF emission spectrum excited with a 12keV electron beam in cw mode

Note, that the membrane and the silicon wafer material has to be protected against reactive etching when using the chemically very aggressive halogen gases such as fluor as described in ref. [5]. The materials of the walls of the cell and gas system also have to be carefully selected to be inert with respect to the halogen gases.

Applications of the VUV lamps for photoionization in mass spectrometers have already been successfully demonstrated [9]. Presently two mass spectrometers are being built at GSF which are specially designed to be used with the novel VUV-photoionization ion sources. Two plano-convex $MgF_2$ lenses with 25 mm focal length at 121.5 nm wavelength are used to provide a 1 to 1 image of the small ($\sim$1 mm$^3$) light emitting volume at the position where the gas sample has to be ionized in the mass spectrometer. This optics in combination with a new quadrupole mass spectrometer has already been successfully tested using a VUV lamp with a preliminary, compact electron gun which has been developed and built by TUM/TuiLaser. Studies on potential new light emitting systems performed by the TUM group in 2003 are described in a separate contribution to this annual report.

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