DEVELOPMENT OF PULSED LASER SYSTEMS AND CATHODE-PERFORMANCE STUDIES FOR THE S-DALINAC POLARIZED INJECTOR*

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Abstract

A source of polarized electrons has recently been implemented at the superconducting Darmstadt electron linear accelerator S-DALINAC. We give an overview of the recent performance of the system. Photo-emission from a superlattice-GaAs photo-cathode is obtained from using either a DC diode laser or a short-pulse Ti:Sapphire laser system. For a robust pulsed quasi-cw operation, it is investigated whether a VECSEL system (Vertical-Cavity Surface-Emitting Laser) can be realized with a wavelength of 780 nm and a repetition rate of 3 GHz with pulse widths of a few picoseconds only. To enhance the availability and performance of the polarized source with respect to quantum efficiency, a separate atomic-hydrogen cleaning system for the cathodes is planned which will allow cathode treatment to be tested and optimized.

INTRODUCTION

The superconducting Darmstadt electron linear accelerator S-DALINAC [1] provides electron beams with energies of a few MeV up to typically 80 MeV with electron and photon beams for a variety of experiments on nuclear and nucleon structure. To extend the physics program to polarization degrees of freedom [2], a new source of spin-polarized electrons based on the photo-emission from strained-superlattice GaAs has recently been installed [3].

The operation principle of this source of polarized electrons has first been suggested by Pierce [4], and it is based on the fact that electrons may be selectively excited from the GaAs valence band into the conduction band through irradiation with circularly polarized laser light, see Fig. 1. Using strained-superlattice structures [5] degrees of above 80% are regularly achieved, assuming full polarization of the laser beam. In order to extract the electrons into the vacuum, negative electron affinity (NEA) is achieved through the so-called preparation process where a thin CsO layer is added to the doped surface of the GaAs crystal. The integrity of this delicate layer strongly affects the quantum efficiency of the system. In the presence of residual gas, the CsO layer deteriorates, and further processes (see below) affect the performance of the cathode.

While the quantum efficiency increases with frequency, the cathodes presently used at the S-DALINAC exhibit a rather narrow maximum of the degree of polarization that is

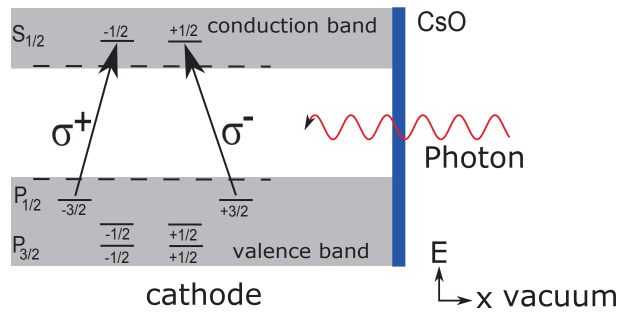

Figure 1: Principle of generating spin-polarized electrons with strained-superlattice-GaAs photo-cathodes.

achieved for wavelengths between 770 and 785 nm. Hence, the laser wavelength must be stable.

The electron beam properties are partly determined by the incident laser beam: Both the transverse properties depend, e.g., on the diameter and position stability of the laser beam spot on the target. If a pulsed laser beam is used, the longitudinal properties of the electron beam are affected, too.

The quantum efficiency of the cathode drops both with increasing residual gas pressure, affecting the vacuum lifetime, and with increasing laser power, giving rise to a finite charge lifetime. The best values at the S-DALINAC so far were (1164 ± 165) h for the vacuum lifetime and (9.6 ± 0.7) C for the charge lifetime. In order to maximally utilize the electron beam for acceleration in the radiofrequency (rf) structures of the S-DALINAC, the generation of a pulsed beam already at the source is highly desirable. A two-stage harmonic prebuncher system [3] is capable of compressing 50 ps incident electron bunches with the fundamental frequency of the S-DALINAC of 3 GHz down to 5 ps for further acceleration. Therefore, bunch lengths of less than 50 ps are needed.

This contribution discusses two aspects: (i) The laser systems used for driving the source of polarized electrons at the S-DALINAC will be presented, and (ii) deterioration processes reducing cathode performance will be addressed with the proposal for an atomic hydrogen cleaning and preparation test stand.

LASER SYSTEMS

At the S-DALINAC different laser systems are used for generation of spin-polarized electrons which fulfill the above discussed requirements. A Ti:sapphire laser and

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an external-cavity diode laser (ECDL) are already in use. Next to this systems a vertical-cavity surface-emitting laser (VECSEL) is proposed for the further development of the electron source.

Ti:sapphire laser system

The Ti:sapphire laser system is characterized by a large available wavelength range, a high output power of 2 W and very short pulse length of a few hundred femtoseconds by using passive mode locking [6]. This system works with a repetition rate of 75 MHz, the 40th subharmonic of the S-DALINAC's fundamental frequency. This system is very sensitive against external influences like temperature drifts. Therefore a thermal insulation and a active water cooling system was installed. In Fig. 2 the room temperature in the lab and the temperature of the laser cavity is shown over time. The temperature stabilization system could damp the temperature fluctuations in the cavity to ± 0.05 K.

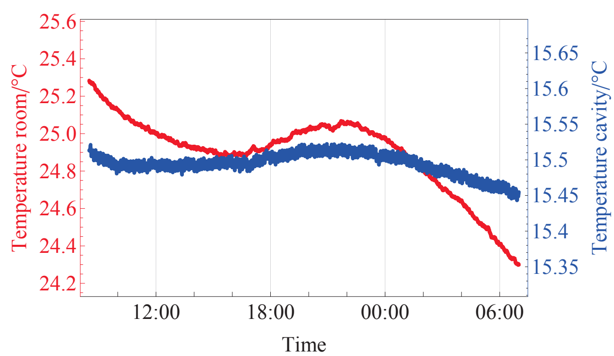

Figure 2: Temperature stabilization of the Ti:sapphire system.

The wavelength, pulse length, and polarization of the laser beam of the Ti:sapphire system are monitored by a dedicated spectrometer, an autocorrelator, and a Stokes polarimeter which have been developed in the framework of Thesis projects. As the peak power of the laser pulses in mode-lock operation reaches 130 kW, the Ti:sapphire beam is transferred via an evacuated beam line over a distance of 40 m to the cathode. A position stabilization removes thermal drifts and low-frequency perturbations up to about 10 Hz and guarantees the position stability of the beam to about 20 μm.

External-Cavity Diode Laser

Next to the Ti:sapphire laser, a ECDL is a very cost efficient system to produce a pulsed laser beam with a repetition rate of 3 GHz. For that the current supply will be modulated with a high frequency signal. This procedure is called gain-switching. By variation of the direct current and the modulation power the behavior of different laser diodes was studied. With this pulsed single-mode laser diodes pulse length of about 25 to 35 ps are accomplished by a repetition rate of 3 GHz [7]. By using an external resonator, consisting of a grating, a very stable operation of this laser system is possible, but compared to the Ti:sapphire system the modulation depth and the output power are lesser.

Vertical-Cavity Surface-Emitting Laser

VECSEL's are state-of-the-art semiconductor laser systems, with an advanced mode control using extended cavities and high power scalability [8]. The principle configuration is shown in Fig. 3. The heart of the VECSEL is a GaAs semiconductor laser chip, which is in an external resonator, consists of an output coupler, an end mirror and a high reflective distributed Bragg reflector-layer (DBR) in the laser chip. By using a saturable absorber mirror (SESAM) as one of the end mirrors, very high repetition rates with high modulation depth and pulse lengths of femto- to picoseconds are possible via passive mode locking. The VECSEL will be optically pumped. The output power of the VECSEL is limited by the pump power and the heat transportation away from the laser chip. Therefore usually a CVD Diamond heat-spreader and a heat sink is used with an active temperature stabilization.

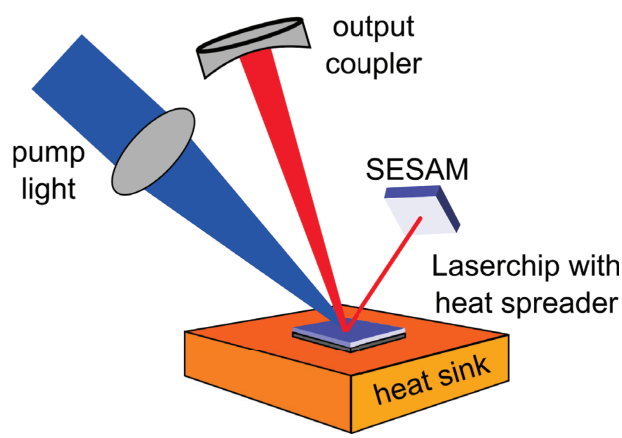

Figure 3: Principle configuration of a VECSEL.

A recent survey [8] has collected a large number of VECSEL applications with wavelengths between 2350 nm and - by using up to 4th harmonic generation - 250 nm. Typical available average power values span about 100 mW to up to some tens of W. In spite of this wide variety of already existing systems, no laser system for the wavelength region that is needed for the present strained-superlattice GaAs photo-cathodes are available. The first task is therefore to identify a suitable laser chip for the VECSEL setup.

ATOMIC-HYDROGEN CLEANING SYSTEM

For further development of the performance of our polarized source, we are planning a new atomic-hydrogen cleaning system to enlarge the cathode charge life time and optimize the preparation process for the photo-cathodes. A first concept of this system is shown in Fig. 4. It includes a load-lock chamber for rapid exchange of cathodes that are transferred to and from the new system via a dedicated transport

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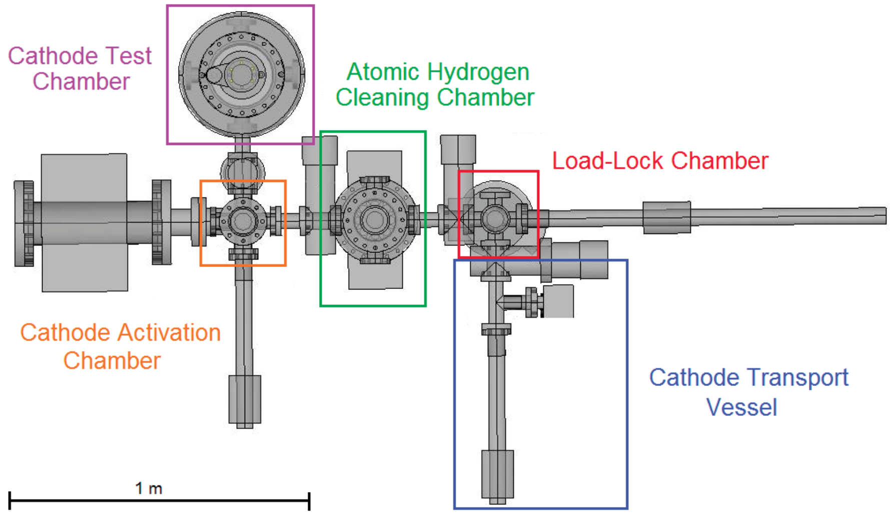

Figure 4: First concept of the new atomic-hydrogen cleaning system.

vessel, so that they can cleaned in the atomic hydrogen cleaning chamber. In the cathode activation chamber the cathodes will be prepared with a cesium oxide layer. In the cathode test chamber the photo-cathode performance can be tested by irradiation with laser light over extended periods, for various cathode materials, preparation and cleaning procedures while varying the laser power on the cathodes.

The cleaning process of the cathodes is foreseen to rejuvenate aging cathodes. With repeated cathode preparation, the preceding values of the quantum efficiency typically cannot be reached anymore. This is due to the influence of the residual gas. Especially carbon atoms are a big problem, because they generate an intermediate layer between the GaAs surface and the cesium oxide [9]. A heat treatment at elevated temperatures in ultra-high vacuum has been found to be inefficient in removing this carbon contamination [10].

The second effect is an aging problem of the cathodes after long-term storage. The cathode surface reacts with oxygen over time. After days the arsenic reacts with oxide and after months gallium(III) oxide is formed, which is hard to remove by heat treatment alone.

Atomic-hydrogen cleaning is a very advantageous procedure to clean photo-cathodes in ultra-high vacuum, which remove all oxides, carbides and other contaminants. The cleaning mechanism works without destroying the base material and favors operation at a low temperature to minimize the material evaporation and cracking of residual gases from other components inside the vacuum chamber. The high reactive atomic-hydrogen binds easily the carbon atoms on the cathode surface. The arsenic oxide reacts with the hydrogen to water vapor and arsenic vapor.

$$\mathrm{As_2O_3} \; + \; 6\,\mathrm{H}^* \; \rightarrow \; 3\,\mathrm{H_2O}\uparrow \; + \; \frac{1}{2}\,\mathrm{As_4}\uparrow \qquad (1)$$

The gallium(III) oxide reacts with the hydrogen to water vapor and volatile gallium(I) oxide [11].

$$\mathrm{Ga_2O_3} \; + \; 4\,\mathrm{H}^* \; \rightarrow \; 2\,\mathrm{H_2O}\uparrow \; + \; \mathrm{Ga_2O}\uparrow \qquad (2)$$

Previous studies at Mainz University [12] have demonstrated that by applying atomic-hydrogen cleaning the quantum efficiency may be restored to almost its initial value, even after extended storage and several preparation cycles and operation.

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