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Status and recent developments at the polarized-electron injector of the superconducting Darmstadt electron linear accelerator S-DALINAC

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Abstract. At the superconducting Darmstadt electron linac a 100 keV source of polarized electrons has been installed. Major components had been tested prior to installation at an offline teststand. Commissioning of the new source at the S-DALINAC will take place early in 2011. We report on the performance of the teststand, simulations, developments on the laser systems, new radio-frequency components for the S-DALINAC injector, and the status of the implementation of the source.

1. Introduction

The superconducting Darmstadt electron linear accelerator S-DALINAC [1] provides electron beams mainly for nuclear structure experiments with energies between 2 and 130 MeV since the early 1990s. Figure 1 shows an overview of the facility with the accelerator and the experimental installations. Behind the superconducting injector linac, experiments with bremsstrahlung are carried out for endpoint energies up to 10 MeV [2]. The main accelerator section is designed for an energy gain of up to 40 MeV, and two recirculating beam lines allow the main accelerator to be passed up to three times.

In the experimental hall a new photon tagger for nuclear structure experiments with photon energies of 5 – 20 MeV (electron energies of 20 – 30 MeV) has been installed [3] as well as a bremsstrahlung setup investigating the polarizability of the nucleon [4]. The workhorses for electron scattering experiments are the two magnetic spectrometers: At a large-solid-angle QClam-type spectrometer coincidence experiments are carried out (see, *e.g.*, [5]) as well as single-arm experiments at 180° (*e.g.*, [6]). A high-resolution magnetic spectrometer is used for inclusive electron scattering experiments (see, *e.g.*, [7]).

So far, the experiments utilize an unpolarized beam produced by a thermionic electron source. However, polarization degrees of freedom can provide access to further observables. Proposed

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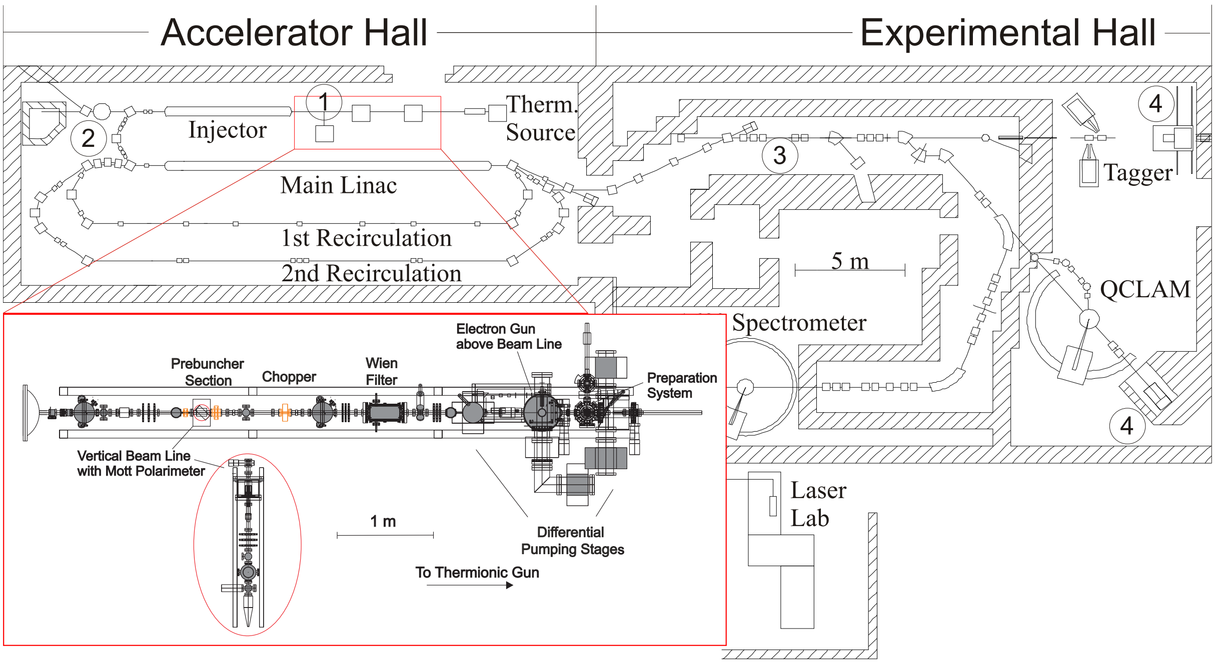

Figure 1. Overview over the superconducting Darmstadt electron linear accelerator S-DALINAC. The polarized source is shown schematically in the inset on the lower left. The polarized source is installed between the thermionic source and the superconducting injector linac and is driven by a laser beam transferred to the source from the laser laboratory. Polarimeters are being constructed for various experimental sites: (1) 100 keV Mott polarimeter; (2) Mott polarimeter and Compton-transmission polarimeter for 5-10 MeV experiments with bremsstrahlung; (3) location of a future 50-130 MeV Møller polarimeter; (4) Compton transmission polarimeters at the tagger system and the QClam magnetic spectrometer.

experiments comprise polarization correlation experiments in bremsstrahlung production (see references [8, 9] for examples), parity non-conservation experiments with regard to photo-induced fission, and, *e.g.*, the measurement of the fifth structure function in electron scattering in light nuclei. A brief account of the latter two experiments' status is summarized in a conference report [10].

As spatial dimensions are limited at the S-DALINAC, a compact source of polarized electrons needed to be constructed. The only suitable location was found to be the normal conducting injection section between the existing thermionic gun – which will remain in use – and the injector linac cryostat. This is indicated in figure 1. The basic layout started from an adaptation of the polarized electron source at the Mainz Microtrons MAMI [11]. The S-DALINAC polarized injector also uses photo-emission of electrons from irradiating a strained-superlattice GaAs cathode. The operation voltage amounts to −100 kV. Prior to installation of the source at the S-DALINAC, the main components have been set up at a separate teststand [12], and the performance of elements of the setup were analyzed in numerical simulations [13].

2. Teststand operation and performance

A schematic overview of the teststand is seen in figure 2. The electron beam is produced from the strained-superlattice cathode held at the tip of an electrode at the high-voltage potential of −100 kV. Separate preparation and load-lock systems provide for the (re-)activation and the fast exchange of cathodes, respectively. At the teststand, a diode laser system was used to irradiate the cathode. Preparation chamber, high-voltage chamber, and the adjacent vertical beam line including a 270° alpha magnet deflecting the beam into the horizontal direction form an ultra-high vacuum (UHV) system with typical pressure below $1.6 \cdot 10^{-11}$ mbar, achieved by ion-getter pumps and non-evaporable getter material. Typical cathode lifetimes, (*i.e.*, the time

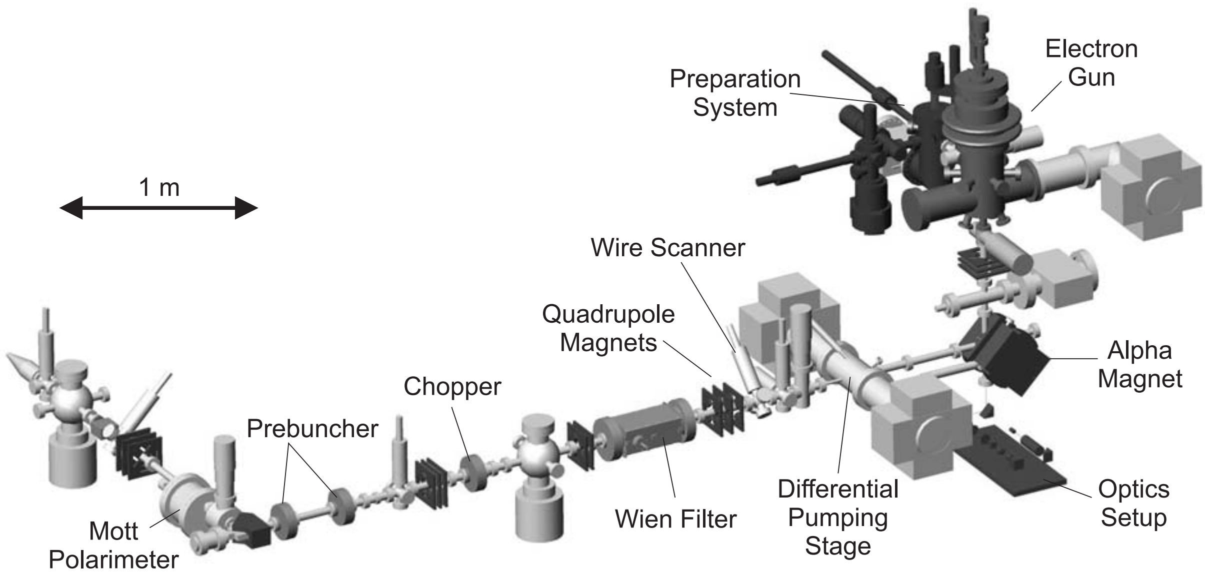

Figure 2. Technical drawing of the teststand of the source of polarized electrons. Electrons are released from a strained-superlattice cathode held at −100 kV in the cathode chamber. The cathode is prepared in an adjacent preparation system. After irradiation of the cathode with a laser beam from below, the electrons are released and guided downward. An alpha magnet deflects the beam into the horizontal direction. Beam transport is realized using short quadrupole triplets. Spin rotation is achieved by a Wien filter. A Mott polarimeter determines the degree of transverse polarization, and wire scanners and fluorescent screens allow for beam profile measurement.

in which the quantum efficiency of the cathode decreases to 1/e of its initial value, amounted to about 100 hours, and a maximum current of above 50 μA has been extracted so far.

In the horizontal test beam line, the polarized electrons leave the UHV system through a differential pumping stage. The electron spin direction can be rotated in the horizontal plane through a Wien filter, and very short quadrupole magnets (10 mm long, 52 mm aperture) are used for focusing of the beam. We note that a challenge in the numerical modeling of the quadrupoles is the handling of overlapping fields that occur since the quadrupoles are grouped in triplets [14].

Beam profiles are measured using fluorescent screens and wire scanners. A double solenoid together with a wire scanner serves as a setup for emittance measurement. Measuring the beam profile as a function of the solenoid's focusing strength allowed us to determine a normalized transverse emittance of the beam. Typical values of $\varepsilon_{n,x} = 0.15(3)$ mm mrad and $\varepsilon_{n,y} = 0.10(2)$ mm mrad were obtained for beam currents between a few nA and about 10 μA (DC operation). The results were – within the experimental uncertainties – very similar for bulk GaAs cathodes and strained-superlattice (high polarization) cathodes.

A Mott polarimeter employing several thin gold foils of varying thickness and housing four silicon surface-barrier detectors at 120° with respect to the incident beam is used for the determination of the degree of polarization. Polarization has been determined for different cathode types and laser wavelengths obtained from different diode laser systems. The maximum degree of polarization measured so far amounted to 86(3)% from a strained-superlattice cathode irradiated by a laser with 830 nm wavelength. Figure 3 depicts measured spectra of two different detectors in the Mott polarimeter that are located opposite of each other. The solid and dashed curves show the measured elastic electron scattering spectra depending on the helicity of the

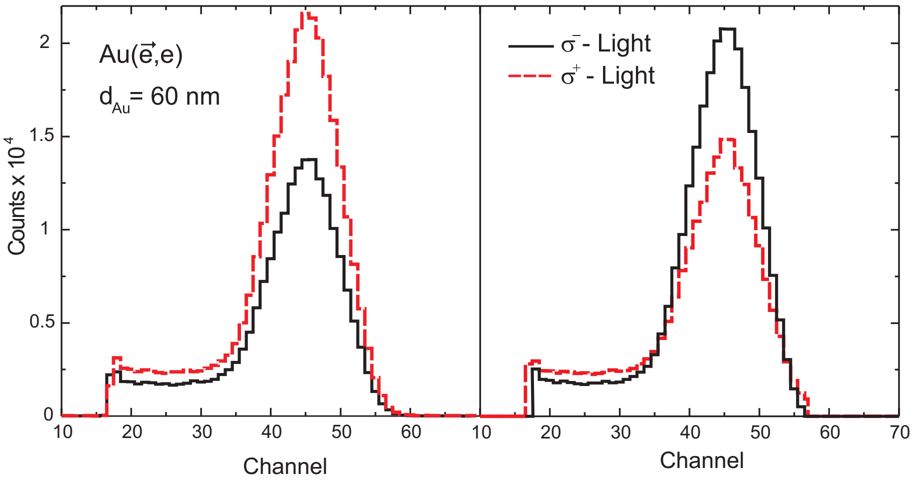

Figure 3. Measured elastic electron scattering spectra of transversely polarized electrons. The spins of the 100 keV electrons are rotated from the longitudinal into the transverse direction using the Wien filter. The two spectra are from two silicon surface-barrier detectors on opposite sides of the beam direction at a polar angle of 120°. The solid (black) and dashed (red) spectra have been taken with left and right circularly polarized laser light, respectively.

laser beam irradiating the cathode. Asymmetries from the integrals of these peaks have been determined for several target thicknesses. The extrapolation to zero thickness then yields the degree of polarization as the analyzing strength (Sherman function) is known for single scattering events only. The uncertainty of the determined polarization degree stems to a large extent from the lack of knowledge of the correct extrapolation of the asymmetries.

The test stand was operated also several times for first experiments in which the bremsstrahlung polarization orientation was measured depending on the orientation of the electron spin, see, *e.g.*, reference [8]. It can be shown that the orientation of the plane of linear polarization of the emitted bremsstrahlung at a given non-zero angle with respect to the beam axis is rotated depending on the degree of longitudinal (and transverse) polarization. Data analysis measuring the degree of linear polarization with a planar high-purity germanium 5x5 pixel detector and a lithium-drifted silicon 32x32 pixel detector are in progress. Beam currents in these experiments ranged from about 1 nA to a few μA with measurement times of several hours to about 1 day per setting.

3. Implementation at the S-DALINAC

Upon successful demonstration of the functionality of the source, it was dismantled at the teststand site and rebuilt at the normal conducting injection beam line of the S-DALINAC. To that end, the existing beam line between the thermionic unpolarized gun and the superconducting injector was removed. The inset in figure 1 shows a schematic drawing of the source at the new location. A second differential pumping stage separates now the thermionic gun from the UHV part of the beam line of the electron source. The preparation chamber was re-arranged, and the downstream differential pumping stage was rotated due to spatial restrictions. Also, the Mott polarimeter is installed in a vertical beam line following a 90° bending magnet due to spatial constraints.

Between the 270° alpha deflection magnet and the entrance into the superconducting injector linac, the beam line is used both for the polarized beam from the new source as well as the beam from the thermionic gun. While the polarized beam has a kinetic energy of 100 keV, the thermionic gun delivers 200 keV electrons, a slight reduction with respect to the former operation voltage of -250 kV. Hence, the beam line must accomodate both beam energies. Besides steering and focusing magnets, this is of particular importance for the radio-frequency (RF) installations.

Although a 3 GHz pulsed operation of the new source had already been shown to be possible from pulsing the diode laser system and utilizing a fast coaxial Faraday cup [12], a new chopper will ensure electron bunch lengths of at most 50 ps. The device consists of a copper cavity, and the design was adapted from the chopper used at MAMI [15]. The functionality of the device had already been demonstrated for the 100 keV beam at the polarized source teststand. To ensure good and efficient acceleration, this bunch length needs to be reduced to about 5 ps at the accelerator entrance. The compression is achieved using a two-stage harmonic prebuncher system, also adapted from the Mainz injector [16]. In addition to a 3-GHz copper cavity, a 6-GHz cavity provides for an increase of the linear regime used for the bunching process. All copper cavities are operated by new RF controls as generator-driven resonators. For the 6 GHz buncher, the standard RF system was modified to accomodate devices suitable for new frequency range. The magnet power supplies for deflecting, steering, and focusing the beam are driven by a new client-server control system via CAN bus.

The superconducting injector linac contained so far three niobium cavities: a five-cell capture cavity and two twenty-cell cavities for further acceleration. Each cavity was operated at a gradient of up to 5 MV/m in continuous-wave mode and had a fixed cell length of 5 cm, corresponding to a phase velocity of the electron bunches of $\beta = v/c = 1$. However, the injection velocity of the polarized beam with an energy of 100 keV only will be lower so that an additional two-cell capture cavity with cell length of 42.5 mm (corresponding to an average electron velocity of $\beta = 0.85$) has been re-installed to reduce phase slippage in the cavities. This capture cavity was first designed and operated in the 1990s [17] and was re-installed with the new source.

For polarization determination during the future operation of the S-DALINAC's polarized source, several polarimeters are being constructred and set up. Besides the 100 keV Mott polarimeter in the normal conducting part of the injector beam line (see (1) in figure 1), another Mott polarimeter has been installed at the experimental site behind the superconducting injector linac where up to 10 MeV electron beams are available (figure 1, (2)). The construction consists of two scintillators at a backward angles of ±165°. Monitoring of the degree of polarization at the injector experimental site will will realized using a Compton-transmission polarimeter described in reference [9]. Behind the main accelerator section, electron beam polarization will be determined by a Møller polarimeter (3) that is being designed for energies between 50 MeV and 130 MeV. Following a basic magnet design, the layout of the detector system is being prepared as is the connection to the accelerator beam line. The challenge with the Møller polarimeter is the low electron beam energy from which large scattering angles of the scattered and recoiling electrons result. At the tagger as well as the QClam spectrometer (points (4) in figure 1) additional Compton-transmission polarimeters are foreseen.

4. Laser system research and development

The new S-DALINAC polarized injector is driven by a laser system based on either a (pulsed) diode laser or a mode-locked Ti:Sapphire laser. Due to the little space available for laser research and development at the site of the source, the laser systems are located at a separate laboratory about 40 m away (cf. figure 1). The diode laser beam is transferred to the source using a polarization-conserving mono-mode fibre, whereas the intense short pulses of the Ti:Sapphire laser (repetition rate 75 MHz, the 40th sub-harmonic of the S-DALINAC's operation frequency) are guided in an evacuated tube. For the latter, an active stabilization with a pointing and centering system is under development. A test stabilization system has already achieved sufficient damping of external perturbations up to a frequency of about 500 Hz.

For the optimization and control of the laser systems, a spectrometer, a polarimeter, and – for the mode-locked operation of the Ti:Sapphire system – an autocorrelator have been developed or are being developed. For the future operation of the source, we are also investigating the possibility of using mode-locked diode laser systems at a repetition frequency of 3 GHz.

5. Outlook

A source of polarized electrons has been tested and installed at the superconducting Darmstadt electron linear accelerator S-DALINAC. We anticipate the commissioning of the new source early in 2011 following the next beam time and the commencement of experiments with polarized beams soon thereafter. Prior to the polarized beam commissioning, the present schedule foresees the operation of the new normal conducting injector beam line with unpolarized electrons from the 200 keV thermionic source.

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