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LASER SYSTEMS GENERATING SHORT POLARIZED ELECTRON BUNCHES AT THE S-DALINAC*

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Abstract

The source of polarized electrons at the superconducting Darmstadt electron linear accelerator S-DALINAC uses photo-emission from strained-layer superlattice-GaAs and bulk-GaAs photocathodes. This system is driven by either 3 GHz gain-switched diode lasers or a short-pulse Ti:Sapphire laser system. Highly polarized electrons are generated with laser light at 780 nm, while blue laser light is used for unpolarized high-current experiments. We present the existing pulsed laser systems and the planned developments for the diode laser system, including, e.g., impedance matching of the diode lasers, gain-switching with short electrical pulses and pulsing with a Mach-Zehnder modulator. The pulsed operation is aimed at generating short electron bunches (<50 ps) at the S-DALINAC with variable repetition rates from some MHz to 3 GHz.

INTRODUCTION

For the superconducting Darmstadt electron linear accelerator S-DALINAC [1] a new source of spin-polarized electrons based on photo-emission from GaAs photocathodes has recently been installed [2] to extend the physics program to polarization degrees of freedom [3].
Highly polarized electrons are generated from strained-layer superlattice-GaAs cathodes by using circular polarized laser light at 780 nm. For unpolarized high current experiments blue laser light at 390 nm and 405 nm, respectively, is used with bulk-GaAs cathodes.
The electron beam properties are partly determined by the incident laser beam: the transverse properties depend, e.g., on the diameter and position stability of the laser spot on the cathode. If a pulsed laser beam is used, the longitudinal properties of the electron beam are affected, too. In order to maximally utilize the electron beam for acceleration in the 3 GHz cavities of the S-DALINAC, the generation of a pulsed beam already at the source is highly desirable. Losses of the quantum efficiency due to degradative of the negative electron affinity surface can be compensated by more laser power to keep the beam current constant during the experiment. Radio-frequency (rf) acceleration requires a bunch structure of the particle beam, and as continuous laser operation generates a continuous beam, a large fraction of the beam cannot be accelerated. Hence the usable charge lifetime of the photocathode is reduced by almost an order of magnitude in continuous mode as compared to pulsed operation. A two-stage harmonic prebuncher system [2] 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.

A Ti:sapphire laser and an external-cavity diode laser (ECDL) are already in use to drive the source of polarized electrons. The Ti:sapphire laser system is characterized by a large tunability in wavelength, a high output power up to 2 W and very short pulse lengths down to a few hundred femtoseconds by using passive mode locking [4]. This system works with a repetition rate of 75 MHz, the 40th subharmonic of the S-DALINAC's fundamental frequency. However it is very sensitive against external influences like temperature drifts. Therefore a thermal insulation and an active water cooling system has been installed.
Complementary to the Ti:sapphire laser, an 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 is modulated with a radio frequency (rf) signal. This procedure is called gain-switching. The behavior of different laser diodes was studied by variation of the direct current (DC) and the modulation power. With this pulsed single-mode laser diodes pulse lengths of under 50 ps are achieved by a repetition rate of 3 GHz [5]. 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 smaller.
This contribution discusses recent development of the diode laser system to achieve a high rf-modulation to generate short single pulses with a variable repetition rate from some MHz to 3 GHz.

RADIO-FREQUENCY-MODULATED DIODE LASER

The idea of a gain-switched diode laser is to generate short optical pulses by using a DC and an external frequency modulated electrical pump pulse as shown in Fig. 1.

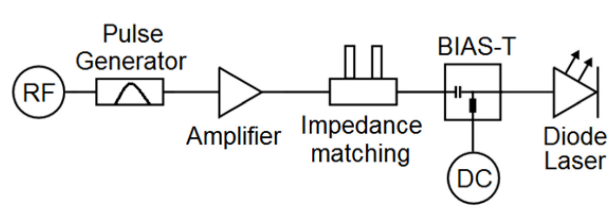

Figure 1: Gain-switched diode laser principle.

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This technique combines the advantages of a variable repetition rate through an external electrical pulse generator and a simple and stable operation of the diode laser. The work principle was simulated with a modified version of [6] and is shown in the figures below. The electrical current increases the electron density in the semiconductor to the laser threshold. At this point the photon density increases rapidly causing a reduction of the electron density. The emitted laser light exhibits relaxation oscillations. For the operation at the S-DALINAC a single laser pulse is needed as shown in Fig. 2. In case of higher rf-amplitude, the electron density exceeds to the laser threshold several times which causes several subsequent laser pulses (Fig. 3). To avoid this, the DC needs to be decreased as shown in Fig. 4 and has to be low for low repetition rates and high for fast modulation frequencies as shown in Fig. 5.
The figures 2 to 5 show that short optical single pulses can be generated at the best with short electrical pulses and an appropriate DC. One can also recognize the disadvantage of a harmonic rf-signal at low repetition rates, where the electrical pulses are too long and generate only broader optical single pulses with lower peak power. This issue can be solved with a picosecond electrical pulse generator providing short electrical pulses with adjustable repetition rate [7].

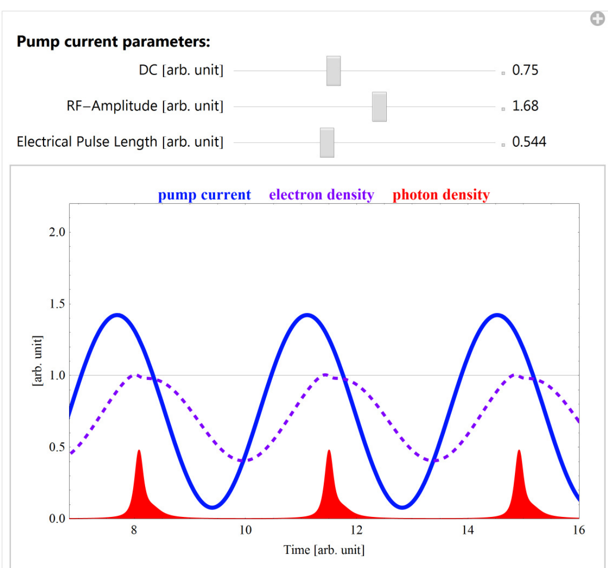

Figure 2: Simulated time signal of a diode laser (red filled line) and electron density in the semiconductor (purple dashed line) in dependence of the pump current (blue line) with the adjustable parameters DC-level, rf-amplitude and electrical pulse length.

FIRST EXPERIMENTAL RESULTS

An advantage of the source of polarized electrons is that the characteristics of the electron bunches depend on the properties of the laser light so that a gain-switched diode laser with a variable repetition rate can be used for time-of-flight experiments at the S-DALINAC.

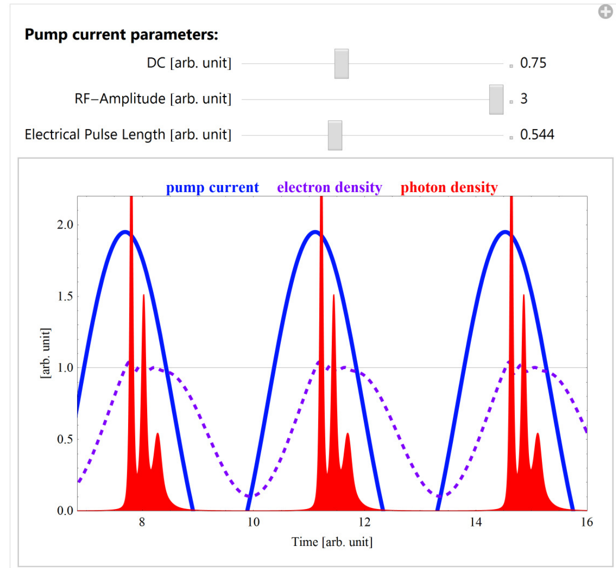

Figure 3: Electron density reaches the laser threshold several times which causes subsequent laser pulses.

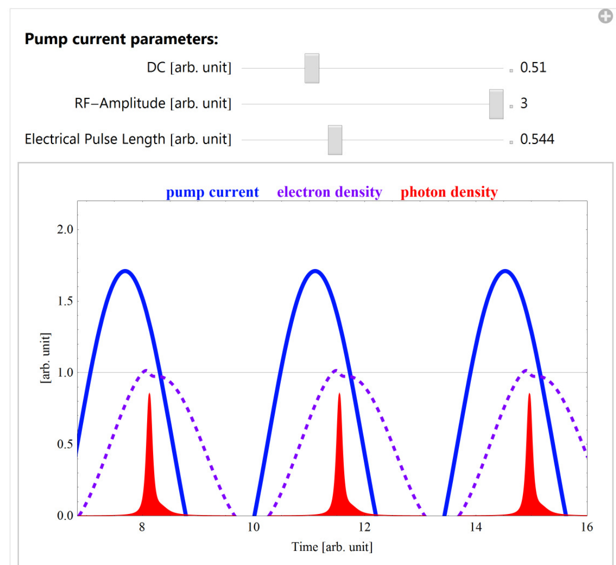

Figure 4: Avoiding subsequent laser pulses with appropriate DC. Optimized single laser pulse with max. peak power reached.

In [5] and [8] 3 GHz modulated diode lasers at wavelengths of 780 nm and 405 nm were tested and laser pulse lengths of about 50 ps were achieved, but with an optical continuous wave (cw)-offset. With a 100 kHz - 20 GHz wideband amplifier [9] it is now possible to modulate these diode lasers in principle with all subharmonic frequencies of 3 GHz. During the first tests we achieved the results shown in table 1 with a harmonic rf-signal and zero DC. Three signals measured from the 150 MHz modulated 405 nm diode laser are shown in Fig. 6, with different rf-input powers, which exactly show the above simulated behavior of several subse-

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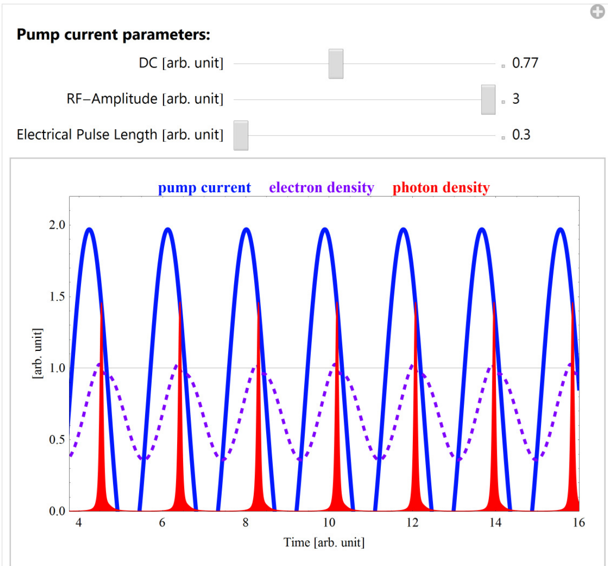

Figure 5: Pump current with shorter electrical pulses generate shorter laser pulses with higher peak power.

quent laser pulses in case of a too high rf-amplitude. These measurements show also no optical cw-offset component.

Table 1: Reached Pulsed Lengths of rf-modulated Diode Lasers

Wavelength	Rep. Rate	Pulse Length
780 nm	3 GHz	50 ps
780 nm	75 MHz	50 ps
405 nm	3 GHz	50 ps
405 nm	150 MHz	100 ps

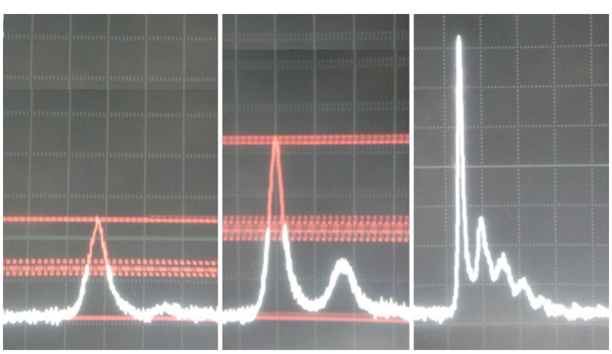

Figure 6: Three time signals of gain-switched 405 nm diode laser, modulated with 150 MHz harmonic signal. Input rf-power: left 26 dBm, middle 27 dBm, right 28 dBm. The first relaxation oscillation of all measurements has a pulse length of 100 ps.

The next step to achieve short optical single pulses is to use a picosecond electrical pulse generator as described above. First tests have shown that pump pulse lengths of about (800-900) ps would be sufficient.

Another important issue for ongoing investigations are - beyond broadband rf-components (amplifier, BIAS-T, etc.) - the impedance matching to the diode laser. In [5] and [8] 3 GHz-stub tuners were used, which achieve good matching conditions for one specific frequency. A good broadband matching solution is a 50 Ω terminator, which prevents the rf-signal from being reflected and causing interference. With the terminator, which has to be parallel and as close as possible to the diode laser, the reflected power was at -10 to -8 dBm from 10 MHz to 10 GHz.

PULSING WITH A MACH-ZEHNDER MODULATOR

An alternative represents a Mach-Zehnder modulator [10]. This is an optical interferometer with a Pockels- or Kerr-cell on one optical arm, which generate a phase shift between the interferometer arms, depending on the applied voltage. In combination with a picosecond electrical pulse generator [7] optical single pulses <50 ps can be generated, with a high losses of laser power if a cw-laser is used. To avoid this, it is recommended to modulate a diode laser before the Mach-Zehnder modulator.

CONCLUSION

The source of polarized electrons at the S-DALINAC is driven by a mode locked 75 MHz Ti:sapphire laser and 3 GHz modulated diode lasers. We showed the theoretical considerations to generate short laser pulses with rf-modulated diode lasers and the experimentally achieved laser pulse lengths at different repetition rates.
Future experiments will investigate single laser pulses with high peak power and repetition rates of 1 MHz to 3 GHz using a picosecond electrical pulse generator.

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