A LASER-ACTIVATED PLASMA SWITCH FOR THE EXTRACTION OF SINGLE FELBE RADIATION PULSES

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Abstract

In order to decrease the average radiation power of the Rossendorf free-electron laser FELBE, as required for certain experiments demanding high pulse energies but moderate or low average power, the FEL repetition rate can be reduced from 13 MHz to 1 kHz. To this end, plasma switching of FEL radiation pulses was demonstrated for cw operation for the first time. The plasma switch is based on the principle of photo-induced reflectivity by an optically excited electron-hole plasma. Germanium serves as semiconductor material for the switch.

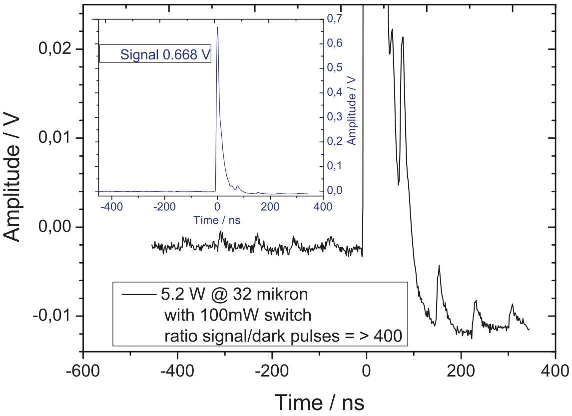

Figure 1: The switched FEL pulse at a wavelength of 32 µm plotted in two different amplitude scales. The comparison of the black and blue curves yields that the parasitic dark pulse have intensities of less than 0.25 % of the switched pulse. The power was 5.2 W at the Ge crystal.

INTRODUCTION

The radiation source ELBE [1] at the Forschungszentrum Dresden-Rossendorf in Dresden is built around a superconducting Electron Linear accelerator of high Brilliance and low Emittance (ELBE), constructed to produce cw electron beams with beam currents up to 1 mA at 12 - 34 MeV. The electron beam is used to generate various kinds of secondary radiation, mainly to drive the two free-electron lasers U27 and U100 in the infrared region (4-250 µm). Starting in the summer 2005, user beam time is offered to external users in the frame of the EC funded "Integrating Activity on Synchrotron and Free-Electron Laser Science" (FELBE project [2]). FELBE is an acronym for the free-electron laser (FEL) at the ELBE accelerator. Twice a year users are invited to submit proposals for experiments at ELBE. For the period February - June 2011 the deadline will be November 15, 2010. Access is free of charge for all non-proprietary research. Proposals are evaluated by the scientific advisory committee of ELBE. Based on its recommendations the final decision and allocation of beam time will be made by a local panel headed by the scientific director of the FZD.

The majority of the accepted proposals require cw operation of the FEL. In order to decrease the average power of the Rossendorf free-electron laser FELBE, as required for certain experiments (high pulse energies but moderate or low average power), the FEL repetition rate can be reduced from 13 MHz to 1 kHz by a plasma switch. This was demonstrated for the first time using cw operation.

MEASUREMENTS

The plasma switch is based on the principle of photo-induced reflectivity by an optically excited electron-hole plasma [3, 4]. Germanium serves as the semiconductor material for the switch. The semiconductor was illuminated by a Nd:YAG laser amplifier system (1 kHz, $\lambda = 1064$ nm, $\tau \sim 16$ ps, $P \leq 1$ W), generating an electron-hole plasma on the front surface of the semiconductor. The generation of a sufficient plasma density leads to a variation of the optical semiconductor properties for the infrared FEL-radiation (strongly focused and under Brewster's angle). For realizing the pulse selection the frequencies of both laser sources (FEL and Nd:YAG) were synchronised with RF electronics. The timing of the arrival of both laser pulses (FEL and Nd:YAG) at the semiconductor surface was detected with photoelectromagnetic detector PEM-10.6 (company VIGO; up to wavelength $\lambda = 25$µm) or a GaAs/AlAs superlattice [6] (self-construction; for wavelength longer than 25 µm) for the FEL and a fast photo diode (Nd:YAG). Subsequent variations in cabel length, an electric phase shifter (trombone) and a precision optical delay stage were used to optimize the temporal overlap of the pulses. Figure 2 shows the experimental set-up. The selected FEL pulses were detected by a fast MCT detector with a bandwidth of 20 MHz. A gold mirror served as a reference for determining the reflectivity of the germanium. For improvement of the ratio of deflected pulse/dark pulse we incorporate a device based on a corner cube for continuous rotation of the polarization direction of the incoming IR beam [5]. This device uses only reflective optics and therefore has a high transmission compared to a free-standing wire-grid polarizer, which normally transmits about 70 %. Hence we are able to adjust the polarization direction of the incoming beam to the Brewster

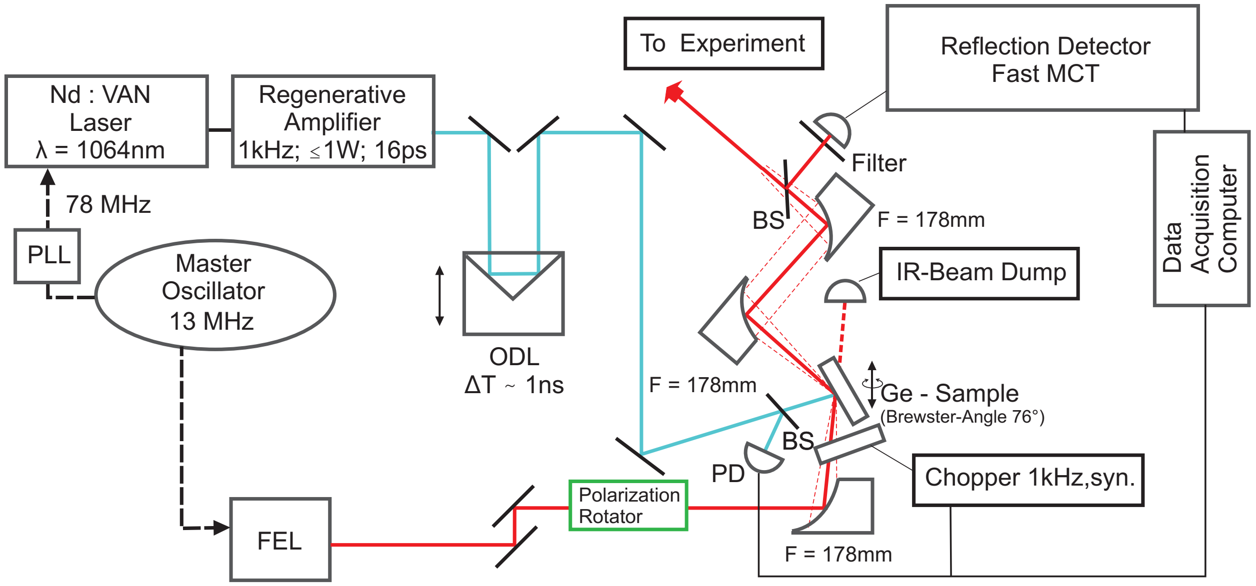

Figure 2: Setup for the plasma switch. For details see text.

plane (p-polarization) of the switch without losses. The FEL power at the Ge crystal was temporary up to 16 W at different wavelength in cw. To overcome the problem of the heat load at the optical switch crystal we incorporated a synchronized chopper in front of the crystal. The spot sizes were about 0.5 mm^2 for the FEL and about 3 mm^2 for the Nd:YAG laser.

Figure 1 shows the switched pulse at $\lambda = 32\mu m$ in two amplitude scales. From the comparison of the black and blue curves we obtained an intensity of dark pulses in the switched beam of less than 0.25 % due to the angle of beam spread from the focusing. For the highest value of the Nd:YAG laser power of 400 mW (corresponding to a fluence of 10-20 mJ/cm^2), a reflectivity of of 100 % was achieved for FEL radiation ($\lambda = 17\mu m$) at Ge (see Fig. 3). At 50 mW power we achieved 100 % reflectivity for a wavelength of $32\mu m$ (corresponding to 1-3 mJ/cm^2). The available Nd:YAG laser energy from maximum 1mJ is sufficient for a 100 % reflectivity down to a wavelength of $\lambda = 11\mu m$ (peak fluence of 25 mJ/cm^2 with a spot size of 1.5 mm^2 for the Nd:YAG). With a stronger focusing of both lasers we achieved 80 % reflectivity for $\lambda = 6\mu m$ (peak fluence of about 80 mJ/cm^2). However, the thermal load of the Ge crystal is very critical.

CONCLUSION

We succeeded to extract single FEL radiation pulses out of the 13 MHz cw pulse train from FELBE, indicating that this plasma switch is most suitable for the Rossendorf FEL. Further examinations will concentrate on achieving similar results for shorter wavelength. To integrate this plasma-switch into the existing diagnostic station we have to build an additional by-pass to the germanium slab which is under Brewster's angle. The selected micro pulse will be refocused to the waist parameters outside of the by-pass line and transported to the user stations.

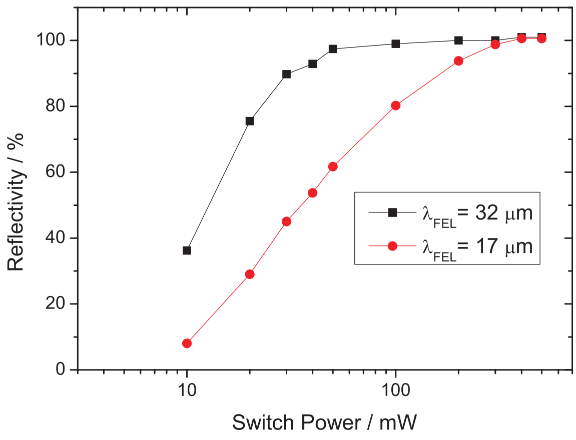

Figure 3: Dependence of reflectivity on pump-laser power for two different wavelengths.

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