TELECOMMUNICATION CONCEPTS FOR COMPACT, ELECTRO-OPTICAL AND FREQUENCY TUNABLE SENSORS FOR ACCELERATOR DIAGNOSTICS*

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Abstract

Terahertz diagnostics for investigating the properties of electron and photon beams, especially the investigation of electron bunch instabilities, accompanied by terahertz photon bursts is increasingly employed to monitor and investigate electron bunch dynamics. Recent advances in information and communications technology promise compact sensors based on telecom and thus industry standards. We present potential applications of such technology concepts for accelerators, including a miniature probe for electro-optical sampling, which could be employed for electron bunch electrical near-field studies, and laser sources with widely tunable pulse repetition rates adaptable for pulsed diagnostics.

INTRODUCTION

Accelerators as part of linear accelerators, free-electron lasers, and synchrotrons operating in a low-alpha mode progress towards the generation of shorter electron packages (bunches) and subsequently to photon emission in short femtosecond to picosecond pulses. Current longitudinal bunch lengths of a micrometer to a few hundred micrometer (in the direction of the electron beam propagation) correspond to time ranges from a few femtoseconds to a few picoseconds. Short bunches give rise to the occurrence of coherent synchrotron radiation (CSR), which is mainly observed in the terahertz (THz) frequency region while 1 THz corresponds to 1 ps. Terahertz diagnostics [1] for investigating the properties of electron and photon beams [2], especially the investigation of electron bunch instabilities, accompanied by terahertz photon bursts is increasingly employed to monitor and investigate electron bunch dynamics [3].

In telecommunications technology, the push for data rates from gigabyte per second towards terabit per second leads to the use of sub-picosecond lasers and terahertz frequency communication, which matches the requirements of current accelerator electron and photon beam diagnostics.

In the following we describe two technologies, which could lead to more flexible and stable femtosecond laser pulse sources and to multi-channel electro-optical spectral decoding technologies in accelerator diagnostics.

TELECOMMUNICATION CONCEPTS

Optical frequency combs are typically based on mode-locked femtosecond lasers. The frequency comb spacing is mainly defined by the geometry of the laser cavity, which can be slightly modified by including temperature-driven or piezo-driven elements. The latter can enable control elements for synchronization schemes. Nevertheless, the change of the repetition rate of the laser and thus the frequency comb spacing is dominated by the geometry. Fiber-based mode-locked lasers often operate in the region with repetition rates of a few tens to hundreds of megahertz best, so that the laser typically needs to be custom-build for the needs of the accelerator.

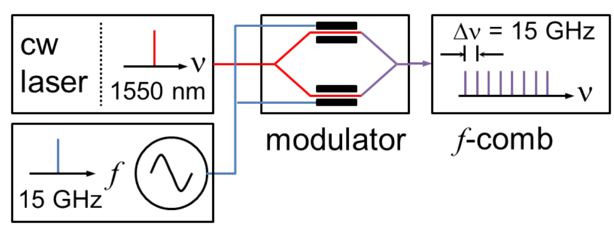

Figure 1: Simplified scheme for the generation of a frequency comb using a continuous wave (cw) laser at a telecom frequency, a radio frequency source at e. g. 15 GHz, and a modulator based on an electro-optical material such as $LiNbO_3$ and individual modulation of each arm in a Mach-Zehnder interferometer. The resulting frequency comb with comb tooth spacing of 15 GHz can be further modified for applications, e. g. compression to a short sub-picosecond terahertz pulse.

In 2008 a new scheme was proposed and demonstrated [4], which uses a continuous wave (cw) laser in the telecommunication frequency band around 1550 nm and a radio frequency (RF) generator in the gigahertz range driving a modulator to generate a frequency comb. Figure 1 shows a simplified scheme. For in-depth information consult the references [4, 5]. The spacing of the frequency comb is easily tunable over wide frequency ranges (several gigahertz) via electronic means only such as the RF generator. Figure 2

* Work supported by Invitation Fellowship for Research ID No. S16704 of Japan Society for the Promotion of Science (JSPS) awarded to E. Bründermann (KIT) hosted by I. Hosako (NICT).
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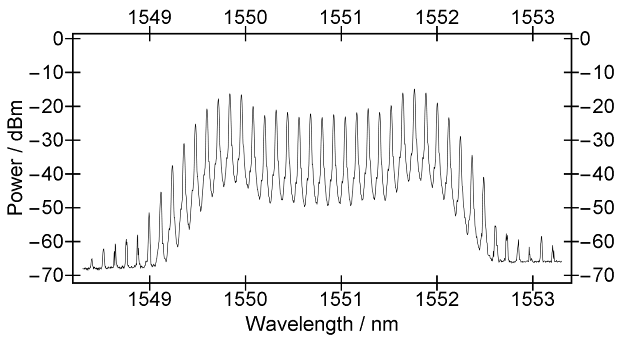

Figure 2: Experimental result of frequency comb generation using a telecom single-frequency continuous wave laser and a $LiNbO_3$ modulator operated with a radio frequency of 15 GHz .

shows an experimental result using a 15 GHz RF frequency to generate a frequency comb. The stability of the frequency comb is related to the stability of the single-frequency telecom laser and the RF generator. Those devices can be further stabilized by tracing them back to time standards such as atomic clocks. In addition, the frequency comb can be used for applications such as the generation of short pulses by compression, e. g. 2.4 ps [4] and recently femtosecond pulses with a full-width at half-maximum of 80 fs [5] were achieved. Such frequency combs could replace conventional mode-locked laser systems currently employed in accelerator diagnostics. The RF, which drive the accelerators could be easily locked to the RF of the frequency comb.

MINIATURE ELECTRO-OPTICAL PROBES

Electro-optical sampling or electro-optical spectral decoding typically employ a single optical path to measure the electron bunch profile [6]. By using fiber technologies well

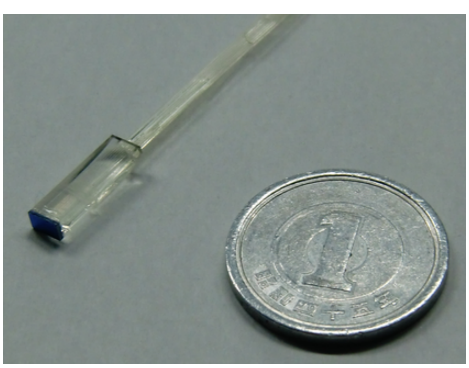

Figure 3: Electro-optical probe integrated with 16 fiber-based channels suited for telecom frequencies around 1550 nm and Japanese 1-yen coin with a diameter of 20 mm and a thickness of 1.5 mm for size comparison.

advanced in the telecommunication frequency range around 1550-nm wavelength allows dense packaging of fibers with small form factors. Figure 3 shows an example of an electro-optical crystal attached to the holder of a dense fiber band consisting of 16 fibers, which can be individually addressed to provide spatial resolution of terahertz transients impinging on the electro-optical material.

CONCLUSION AND OUTLOOK

We have shown the possibility to generate frequency combs with easily tunable comb spacing via a RF generator in a $LiNbO_3$ modulator and discussed their possible applications in accelerator diagnostics.

Telecommunication technologies are driven by a large market and industry demand. This leads to key technologies, which are highly reliable, stable, rugged, with potentially long lifetime and low costs. In addition, such technologies are often scalable and can be parallelized.

The push for data rates from gigabyte per second towards terabit per second leads to the use of sub-picosecond lasers and terahertz frequency communications, which matches the requirements of current accelerator electron and photon beam diagnostics. Thus, accelerator diagnostics can profit from such advances by incorporating these technologies. Electro-optical spectral decoding for electron bunch diagnostics could benefit from moving to the 1550-nm telecommunications band.

The combination of optical technologies [5] and high-speed electronics [7] could open new windows to cost efficient and reliable accelerator diagnostics.

ACKNOWLEDGEMENT

The work is supported under the Memorandum of Understanding (MOU) between KIT and NICT to encourage cooperation in the field of information and communications technology and accelerator research and technology with consideration of lasers, topics of timing and synchronization, stability of systems, and data science.

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