MEASUREMENT OF THE OUTPUT POWER IN MILLIMETER WAVE FREE ELECTRON LASER USING THE ELECTRO OPTIC SAMPLING METHOD

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Abstract

In this experimental work an electro optic (EO) sampling method was demonstrated as a method to measure the output power of an Electrostatic Accelerator Free Electron Laser (EA-FEL). This 1.4 MeV EA-FEL was designed to operate at the millimeter wavelengths and it utilizes a corrugated waveguide and two Talbot effect quasi-optical reflectors with internal losses of ~30%. Millimeter wave radiation pulses of 10 µs at a frequency of about 100 GHz with peak power values of 1-2 kW were measured using conventional methods with an RF diode. Here we show the employment of an electro-optic sampling method using a ZnTe nonlinear crystal. A special quasi optical design directs the EA-FEL power towards the ZnTe nonlinear crystal, placed in the middle of a cross polarized configuration, coaxially with a polarized HeNe laser beam. The differences in the ZnTe optical axis due to the EA-FEL power affects the power levels of the HeNe laser transmission. This was measured using a polarizer and a balanced amplifier detector. We succeeded in obtaining a signal which corresponds to the theoretical calculation.

INTRODUCTION

Continue Wave (CW) and pulsed millimeter wavelength (MMW) and Terahertz (THz) radiation have many applications in medicine, industry, military and security [1]. In order to realize those applications, knowledge of the MMW or THz beam properties such as beam power, beam diameter and beam cross section pattern are required. For the MMW Electrostatic Accelerator-Free Electron Laser (EA-FEL) operating at 100 GHz we used heterodyne detection and received good results [2]. For higher frequenc radiation and pulsed sources, photoconductive antennas and far-infrared interferometric techniques are used [3, 4]. Photoconductive antennas have higher responsivity, and their signal-to-noise ratios are better than liquid helium cooled bolometers. Their detection bandwidth with a short dipole length can exceed 1-3 THz. The drawback of those photoconductive antennae is the resonant behavior and the limited operating bandwidth. Interferometric techniques provide an autocorrelation of terahertz pulses but important parameters of the beam are lost and it is complicated to realize. In this study, we report the use of an alternative optoelectronic method, free-space electro-optic sampling [5], to characterize freely propagating terahertz bandwidth CW or pulsed electromagnetic radiation. The advantages of this method are the sensitivity and speed of response allowing the identification of a short pulse envelope. Also this method can detect the cross-section of the THz beam radiation. In this work we demonstrated power measurements of single pulses and in-the future we intend-to image the cross sectional pattern of MMW and THz pulses. Our detection is independent of the source of MMW and we use inexpensive components, which include a HeNe CW laser, detector, optical components and two off-axis parabolic mirrors (OPM) to focus the MMW beam onto the ZnTe Elecro-Optic (EO) crystal cross section (see Fig. 1).

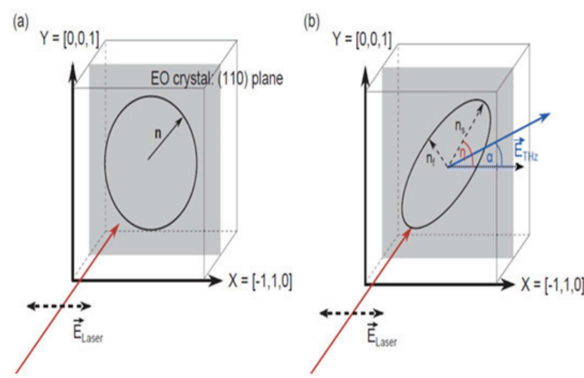

Figure 1: Refractive index ellipsoid of ZnTe Electro Optic crystal (a) Symmetric ellipsoid, without electric field and (b) The directions and the magnitudes of the main axes are changed, when an electric field is applied.

THEORY

Electro-Optic Effect in ZnTe [6, 7]

The EO crystal ZnTe exhibits a birefringence, which means a different refractive index property along the propagating direction of a laser beam. Each refractive index is linear dependent on the electric field's strength. This effect is called Pockels effect.

The direction of the axes and the dependency of each refractive index can be calculated by considering the constant energy surface of the electric displacement vector space and the impermeable tensor which is linear in the electric field. The main refractive indices can be known from the refractive index ellipsoid equation by a principal-axis transformation. For a ZnTe crystal cut in the 110 plane, polarized laser light enters the crystal with amplitude equal to the two main axis, the different refractive index in each one cause to different phase between them [3].

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$$\cos(2\eta) = \frac{\sin(\alpha)}{\sqrt{1+3\cos^2\alpha}} \tag{1}$$

where α is the angle between Electric THz field to X axis, η is the angle that determine the new primary axes of refractive indexes.

$$\Gamma = \frac{w_0 d}{c}(n_1 - n_2) = \frac{\pi d}{\lambda} n_0^3 r_{41} E_a \sqrt{1+3\cos^2\alpha} \tag{2}$$

$$\text{For } ZnTe,\ r_{41} \cong 4.04 * 10^{-12}\,\frac{m}{v} \tag{3}$$

where λ is the wave length of the laser beam, d is the crystal thickness, n_0 is the initial refractive index, r_{41} is the electro-optic constant and E is the electric field strength.

The difference of the propagating speed due to different refractive indexes, changes the polarization of the incident laser beam. This difference can be represented as a relative phase shift between the two components of the new primary axes directions.

The output power in the cross polarizer scheme is:

$$\Delta I = I_0 \sin^2\left(\frac{\Gamma}{2}\right) \tag{4}$$

EXPERIMENTAL SETUP

A block diagram of MMW radiation power measurements based on the EO sampling method is shown in Fig. 2. The EO sampling is based upon a ZnTe EO crystal (see Fig. 1). A polarized MMW beam from the EA-FEL is transferred to the input aperture. A 1.2 mW CW HeNe laser operating at 633 nm is used as a probe beam. The laser beam is polarized by an input polarizer and it is perpendicular to the EA-FEL beam. The laser beam is focused on a ZnTe crystal, coaxially with the measured EA-FEL 100 GHz beam. An off axis parabolic mirror (OPM) is used to focus the EA-FEL beam on the crystal. The laser beam is transferred through a hole in the OPM. The ZnTe crystal cut is 110 and its size is 10*10*1 mm (see Fig. 1). The laser beam after the analyzer is directed to one of the photo diodes in the balanced detector. The photodiode signal is measured using an oscilloscope.

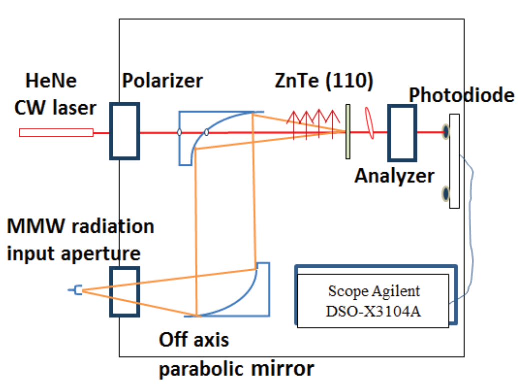

Figure 2: Experimental set-up for measuring the pulsed beam radiation using EO crystal ZnTe.

EXPERIMENTAL RESULTS

The power results measurement of the FEL power are shown in Fig. 3 for three conesecutive pulses. The pulse duration was measured to be 6μs with power of about 1-2 kW. In the top graph the results of measurements with the EO detector and in the bottom graph for the same pulses the power profiles measured by an RF diode.

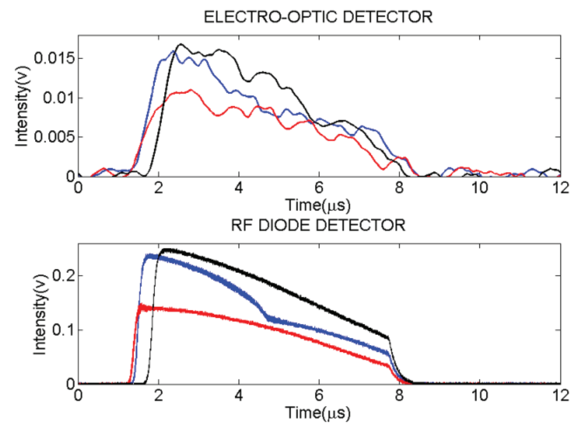

Figure 3: Experimental results for measuring the pulsed beam radiation using the EO crystal ZnTe (top graph) using the configuration of Fig. 2.for comparison the same pulses were measured simultaneously using an RF diode.

The experimental results of the RF diode confirm the correctness of the power measurements using the EO sampling method.

FUTURE FOLLOW-UP EXPERIMENT

Our next step is to obtain a cross sectional image of the EA-FEL beam pattern. For that we have to expand the detection system by using higher power laser and beam expander to overlap the MMW beam from the EA-FEL. The influences of the MMW beam cross section on the ZnTe crystal properties and consequently on the laser beam will be captured a using sensitive CCD camera.

SUMMARY AND CONCLUSION

For 100 GHz, 2-10 μs pulse with about 1-2KW of input power, a good electro-optic signal was obtained. The signal was compared with a signal from a well-known RF Diode detector. The EO sampling method provides the ability to measure much shorter pulses due to the fast response of the ZnTe crystal. Imaging of the cross section of the EA-FEL MMW beam can be carried-out. Unlike RF diode detectors, no RF attenuators are required. The power measurements demonstrated in this study are broadband, mobile and independent of the MMW or THz source.

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