

High-power, tunable source of coherent THz radiation driven by a microbunched electron beam.

I. V. Konoplev, H. Zhang, G. Doucas

Department of Physics, University of Oxford, Oxford, OX1 3RH, UK

Abstract—“Pre-bunched” or “microbunched” charged particle beams have attracted significant interest in the last decade. Potential applications of such beams include development of the next generation of THz and X-ray light sources. This work presents the conceptual design of a tunable source of coherent Smith-Purcell THz radiation based on plasma-assisted pre-modulation of the continuous beam, and conditioning of the micro-bunched beam. The numerical simulations were carried out from the beam modulation to THz radiation generation using a self-consistent numerical model as well as a semi-analytical approach. Such a source would be a possible and useful alternative to conventional vacuum THz tubes and THz FEL sources.

Keywords—coherent THz radiation; Smith-Purcell radiation; non-destructive electron beam monitoring; femtosecond resolution.

I. INTRODUCTION

Trains of microbunched electrons (femtosecond duration electron beam bunches with femtosecond periodicity) have been considered for a wide range of research and applications, including HP tunable sources of coherent terahertz (THz) and x-ray radiation (Compton sources and FELs), wakefield-based particle acceleration, etc. The study of the THz radiation generated by a micro-bunched beam is one of the fast developing areas. This paper discusses the modulation of an initially continuous beam in a plasma channel (i.e. the generation of the microbunched beam), the subsequent beam propagation and the generation of THz radiation by the interaction of the beam with a metallic grating (the Smith-Purcell radiation). We present the results of numerical studies of the beam modulation in a plasma, discuss the beam properties required for the effective generation of THz radiation, and present the concept of the THz radiation source.

II. THEORY

Coherent Smith-Purcell radiation (cSPr) is emitted when a short (in comparison with the generated wavelength) charged particle beam propagates in the vicinity of the surface of a periodic structure (grating) [1-7]. The energy generated by the bunch of the relativistic electrons is proportional to the square of the number of the electrons in the bunch. It was demonstrated [3-6] that if the beam is microbunched the radiation generated by the microbunches which are located simultaneously above the same grating is coherent and its frequency is determined by the micro-bunch spacing [4]. The concept can be used to design source of the high intensity, THz coherent radiation [5-6].

The use of the cSPr is attractive due to: simple tuneability of the cSPr; possibility to observe narrow spectrum line (below 0.1% of the operating frequency); high stability, purity and intensity (above kW power level) of the radiation, and the source of the radiation can be compact and relatively efficient. There are three scale parameters associated with such radiators and which define the properties of the radiation: the number of the grating periods N_{gr} , the number of microbunches in the train N_b above the grating at any instance and the periodicity of the microbunches T_b [3-6]. These parameters give: the minimal width of the radiation single line in the far field zone $\delta\omega \sim \omega/N_{gr}$ (spectral resolution); the width of the main spectral lobe generated $\Delta\omega \sim \omega/N_b$, and the main lobe's central frequency $\omega_0 \sim 1/T_b$. It should be noted that the spectrum generated by a single femtosecond bunch is broadband and roughly defined the bunch length [1,2]. Assuming that the efficiency of the interaction of the electrons with the gratings in a single bunch and in the train of the microbunches is the same, one may expect increase in the amplitude of the generated signal by the bunch train as compared with the single bunch (assuming the same number of electrons in both cases). The enhancement of the efficiency of the radiation generation is due to the reduction of the space charge i.e. better focusing and stability of the beam and non-linear interaction of the incoming microbunches with the wake fields of the forward bunches which have finite non-zero Q-factors. In this work we present the concept of a source of coherent THz radiation driven by plasma channel microbunched relativistic electron beam, we look at the interaction of a single bunch and a microbunched electron beam and discuss the possibility of improving the efficiency of the source, making it acceptable for both research and industry.

III. REFERENCES

- [1] G. Doucas, V. Blackmore, B. Ottewell, et al., Phys. Rev. STAB 9, 092801 (2006).
- [2] H. L. Andrews, F. Bakkali Taheri, J. Barros, et al., I. V. Konoplev, et al., Phys. Rev. STAB 17, 052802 (2014).
- [3] H. Zhang, I. V. Konoplev, A. J. Lancaster, et al., Appl. Phys. Lett. 111, 043505 (2017).
- [4] Y. Liang, et al., I. V. Konoplev, et al., Appl. Phys. Lett. 113, 171104 (2018).
- [5] H. Zhang, I. V. Konoplev, G. Doucas, J. Smith, Phys. Plasmas, 25, 043111 (2018).
- [6] H. Zhang, I. Konoplev, G. Doucas., J. Phys. D: Appl. Phys., 53, 105501 (2020).
- [7] A. J. MacLachlan, C. W. Robertson, I. V. Konoplev, et al., Phys. Rev. Appl., 11, 034034 (2019)