STATUS OF WORK ON LASER ELECTRON ACCELERATOR WITH ENERGY GRADIENT 1 GEV/M

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Abstract

Status of experimental work on vacuum laser acceleration with grating accelerating structure is presented. Details of structure manufacturing technology are given, elements alignment with submicron accuracy is considered, CO_2 laser system is described.

INTRODUCTION

Attaining the accelerating gradient up to and above 1 GeV/m is critical for development of the future high energy electron accelerators. Laser acceleration in vacuum is one of the ways to resolve this difficult problem. Our laser accelerating structure [1,2], which prototype is [3], is shown schematically in Fig. 1.

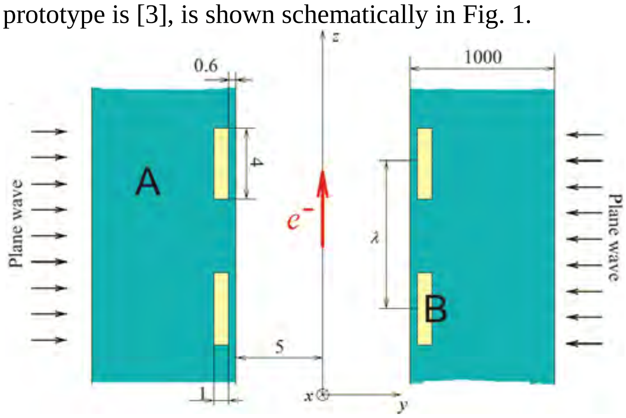

Figure 1: Diffraction accelerating structure. A –dielectric slab (ZnSe, $\varepsilon = 5.773$), B – conducting strip (Al). All dimensions are in μm.

Structure consists of two gratings deposited at dielectric slab, placed at about one wavelength from each other. To eliminate transverse field components it is irradiated from opposite sides by two plane waves in antiphase. For optimized grating and dielectric parameters the longitudinal electric field distribution in median plane is similar to one of the π - mode RF structure and so should provide beam acceleration with high efficiency. To have sufficient space for beam we chose 10.6 μm CO_2 laser radiation as a field source. Maximum accelerating gradient which can be reached in our structure is limited by ablation threshold which is dielectric material and pulse duration dependent. Experimental study of different dielectrics damage by CO_2 laser radiation [4] demonstrated that ZnSe is among the appropriate materials for manufacturing accelerating structure. Maximum measured fluence at pulse duration $\tau = 200$ ps is $F \approx 0.45$ J/cm^2, and at $\tau = 200$ ns, $F \approx 2$ J/cm^2 [4]. Accelerating gradient in our structure is $G \approx \sqrt{\frac{FZ_0}{\tau}}$, where $Z_0 \approx 377$ Ωm, so taking into account threshold dependence on pulse duration we expect to get for our structure gradient ~0.25 GeV/m at $\tau = 10\text{-}20$ ps.

For practical realization of the laser accelerating structure it is important to develop technology for structure manufacturing, to be able to align structure elements and to have laser system with appropriate parameters. In our report these three items are considered.

MANUFACTURING TECHNOLOGY

In Fig. 2 we show surface image of our grating structure prototype obtained with microinterferometer MII-4. Prototype was manufactured with the technology of the threaded gratings with special dividing machine. For manufacturing of ordinary reflection and diffraction gratings the strokes are sequentially cut by diamond cutter in metal layer. The strokes have step-wise profile which is provided by triangular form cutter. For our structure manufacturing special diamond cutter with trapezoid working side was made with which part of metal deposited at substrate was removed. As a result we obtained a hundred of 4 μm wide and 1 μm high Al strips deposited at transparent substrate with period 10.55 μm. To get structure dimensions with good accuracy cutter working side was several times narrower than the width of the transparent part, so metal removal was made in several steps under computer control [5].

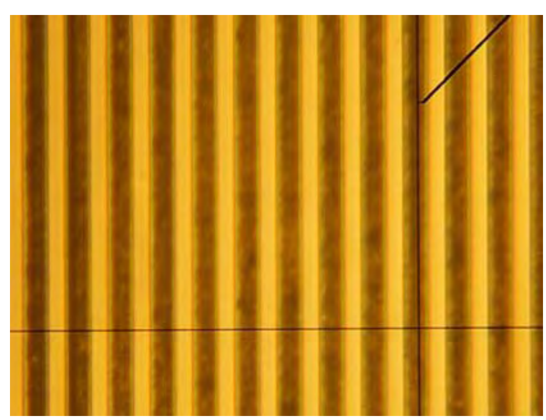

Figure 2: Accelerating structure surface obtained with microinterferometer MII-4

After getting relief structure the substrate side which is irradiated by laser light was subjected to blooming procedure, while ZnSe layer was deposited at side with metal strips. The deposited layer thickness must be about two times more than the strips height, the excessive layer thickness was removed by polishing. The grating side view obtained with electron microscope is seen at Fig. 3.

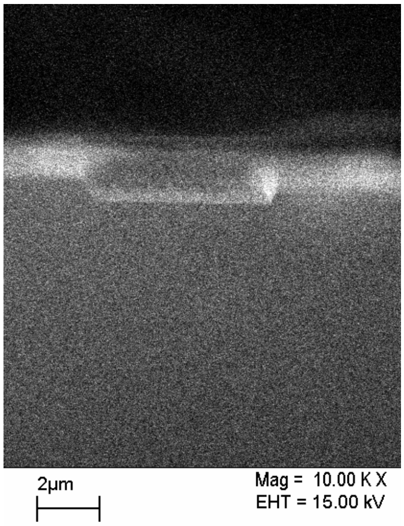

Figure 3: Accelerating structure side view obtained with electron microscope

STRUCTURE ALIGNMENT

To provide necessary field distribution in our accelerating structure and to conduct experiments with the beam two gratings must be aligned with accuracy ~ 0.1 µm with respect to each other and with respect to electron beam. We are to have possibility to adjust distance between gratings during experiments in the range of about 10 µm with step about 0.1 µm.

We plan to conduct experiments of two types with the beam: in the first experiment low energy electron beam passes along the grating strips and produces at the luminescent screen characteristic pattern, depending on field distribution and amplitude; in the second experiment relativistic high energy low emittance beam is energy modulated passing perpendicular to the strips and its energy modulation is registered by spectrometer.

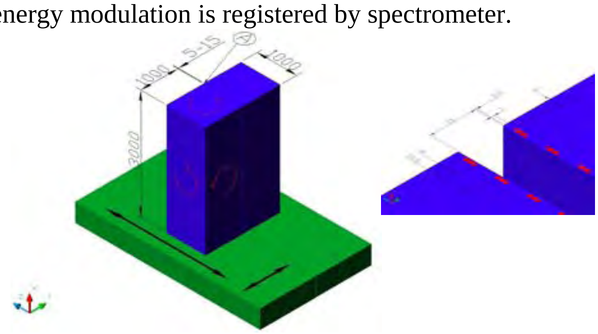

Figure 4: Principle of structure alignment

In Fig. 4 we demonstrate structure alignment principle for experiments with relativistic beam. The gratings are cut off from ZnSe block with accuracy sufficient to use their sides as a base. One grating is fixed (glued) at an immovable platform and the other at platform, which can be moved in three directions with piezoelectric device.

Modern piezoelectric devices used in nanotechnology have sufficient accuracy and range to provide our structure alignment with necessary accuracy [6], however during experiments the gratings position can drift from nominal one because of heating by the laser and electron beams. So the key problem is the adjustment via the feed-back loop the gratings position, which require development of the methods for precise (better than 0.1 µm) control of their position.

LASER SETUP

The experimental laser setup is shown in Fig. 5.

Figure 5: Experimental laser setup

The main unit of experimental setup is a CO_2 TEA laser with 3x3x100 cm active volume. The operation pressure of $He/N_2/CO_2$ mixture is about 300 Torr, and energy is supplied by a 0.1 µF capacitor charged to 35-40 kV. The laser resonator consists of a pair of flat mirrors with 0.96 and 0.3 reflection index. The laser radiation output is a 100 ns pulse of peak power above 1 MW (peak intensity in the focal region over acceleration structure is above 10^{10} W/cm^2).

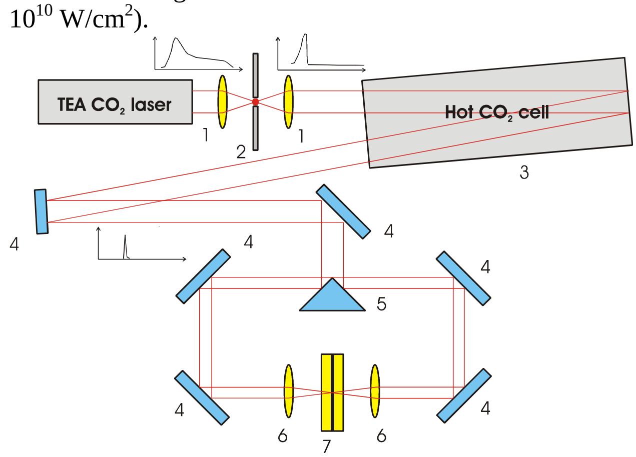

Figure 6: A block diagram of the experimental optical scheme

So significant density of energy at a surface of accelerating structure will lead to its destruction by a thermal hit. A picosecond short-pulse CO_2 laser generation allows avoiding thermal destruction but is a complex technical problem. It cannot be solved by mounting additional elements in the CO_2 TEA laser resonator and is solved by high-speed optical shutter. The simplest design of such optical shutter has been suggested in [7] and is used in our work. The scheme of the shutter is shown in Fig. 6.

The laser beam is focused and recollimated by a 2.5-cm focal length lens pair (1)-(1). Between them, at the focus, a plasma is formed blocking off transmission of the beam. Plasma triggering and control is achieved by allowing the diverging beam to be slightly clipped by a metal iris (2) situated just beyond the focus. Displacement of the iris through small distances along the beam axis allows the breakdown point to be set at a range of position on the temporal profile of the laser pulse, thus giving various possible values of breakdown intensity. The output laser pulse is sharply picosecond cut off by the triggered plasma shutter and the hot CO_2 absorption gas cell (3) served as an optical free induction decay source producing a precession pulse at the instant of the cutoff. Application of the absorption tube has allowed to get 30-picosecond CO_2 laser pulses [8]. The peak power efficiency of the short pulse shutter was close to 40 %.

The short laser pulse is directed to a polarizer and a rectangular mirror prism (5). Two identical laser beams are focused by two cylindrical lenses (6) and system of reflecting mirrors (4) on opposite surfaces of accelerating structure (7), providing required distribution of a electromagnetic field inside this structure.

CONCLUSION

We are developing technology for grating laser accelerating structure manufacturing and have now several prototypes which will be used in upcoming experiments with laser and than also with electron beams.

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