High Power THz Applications on the NovoFEL

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Abstract— **High power THz applications on the Novosibirsk terahertz free electron laser are described.**

I. Status of the NovoFEL

A full-scale NovoFEL based on a microtron-recuperator accelerating system will consist of three free electron lasers operating in the terahertz, far infrared, and infrared ranges (Fig1). The first of them (marked 1 in Fig.1) was put into operation for user applications in 2004. Recently (April 2009) lasing on the second far infrared laser (marked 2 in Fig.1) was obtained. Now this laser is at the debugging and optimization stage. We plan to install a transport radiation channel from the laser to user stations in October 2009.

Now the Novosibirsk terahertz free electron laser is the most powerful source of terahertz coherent radiation in the world. It can produce radiation with an average power of up to 500 W and pulse power of up to 0.5 MW in a spectral range of 110 – 235 μm with a spectral width in the stabilized regime of 0.3 % [1].

In this paper, a short review of various user applications of the powerful NovoFEL terahertz radiation are presented.

II. High-power Terahertz Experiments

All high-power terahertz experiments on the NovoFEL can be divided into two large parts. The first part of the works is to create, test, and use various equipment for this specific radiation. There are various calorimeters, 2D imaging systems [2], spectrometers and spectral filters [3], and various detectors - from simple THz sensors to ultra-fast detectors to measure of the pulse power and light pulse structure with a picosecond rise time [4]. Two illustrations of using this equipment are shown in Fig.2 and Fig.3. The first one is an image of a THz NovoFEL beam on a Macken Instruments termofluorescent plate. The second one shows the NovoFEL THz light pulses registered by the ultra-fast Schottky diode detector. In the experiment, we can see the light pulse extension by a D_2O gas cell. Two D_2O absorption lines were located on both sides of the laser line and decreased its spectral width.

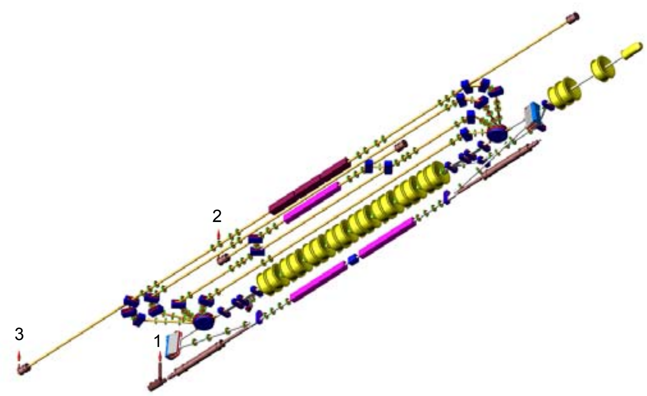

Fig.1. 3D-scheme of the NovoFEL: 1, 2, 3 - radiation output of THz, far infrared and infrared FELs, respectively.

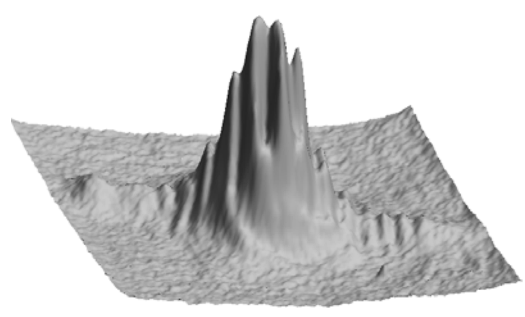

Fig.2. 2D-image of the NovoFEL THz beam. Interference fringes are the result of interference of the main beam and weak halo radiation reflected from the walls of optical transport channel.

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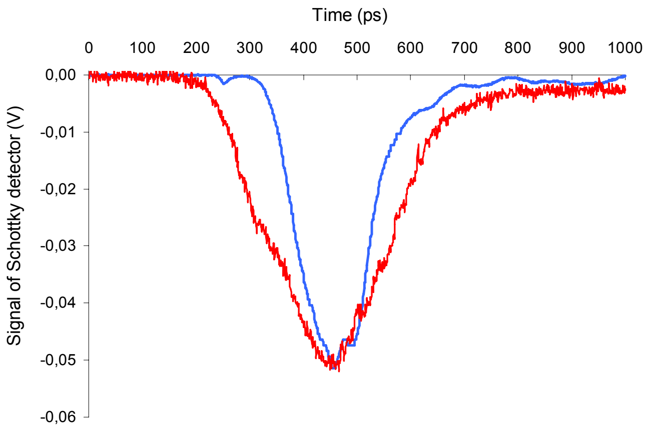

Fig.3. Extension of the NovoFEL light pulse by an absorbing D_2O gas cell: input pulse (blue line), output pulse (red line).

The second series of experiments deals with the application of THz radiation and above-mentioned THz equipment for pure user investigations in different fields of science. The first high power demonstration experiments were performed after the commission of the NovoFEL in 2004. These were laser ablation of polymethylmethacrylate and a sulmillimeter optical discharge [5]. The first phenomenon was further intensively developed in the field of biology. A peculiarity of THz laser radiation is a relatively small energy quantum. Therefore it can destroy weak hydrogen and Van der Waals chemical bonds without destroying covalent bonds in a molecule. As a result, a large biological molecule is ablated as a unit. In many cases it retains its life activity. This specific soft ablation has a lot of applications in modern biological technologies [6]. A scheme of one of the applications is shown in Fig.4. It is a diagnostic biochip technique for biochemical and clinical analyses.

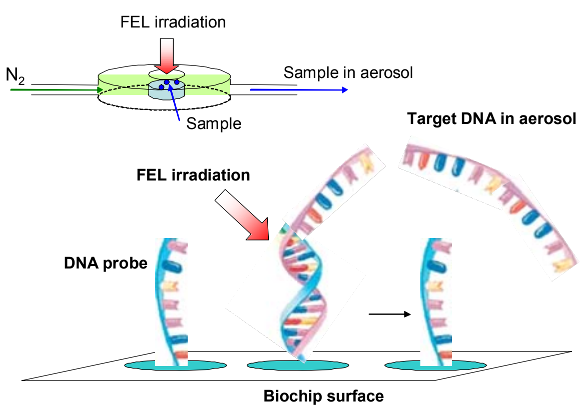

Fig.4. Scheme of soft ablation in biochip technology.

Many experiments were performed to study material properties. The phenomenon of soft THz ablation is shown to be very suitable for investigations of mass fractional composition of nanopowders and nanoclusters in a complex mixture. Such analysis was much faster and more informative in comparison with classical methods SEM, AFM, and DLS (Fig.5) [7].

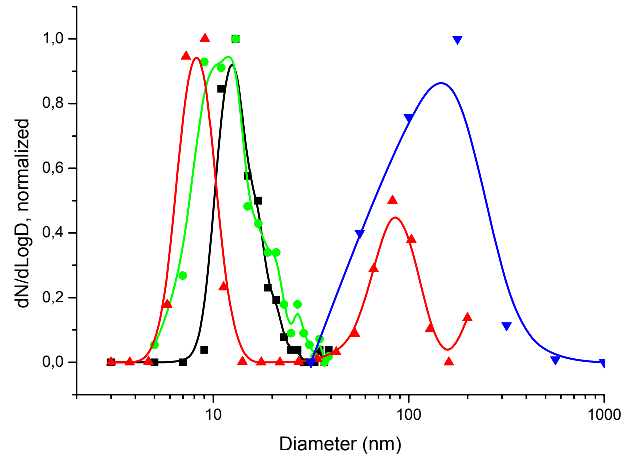

Fig.5. Fractional composition of a nanodiamond in the commercial product of the material: AFM method (green line), SEM method (black line), DLS method (blue line), and soft THz ablation method (red line). THz ablation was made without any special preparation of the sample.

Many optical materials for high-power THz waves were investigated. The main of them is the CVD-diamond, which has unique parameters for THz and far infrared radiation. It is used in the NovoFEL not only as a routine output window in the optical resonator and a transport channel, but also it is regarded as a beamsplitter in an ideal uniform outcoupling system, which can increase the NovoFEL output power more than twice [8]. In spite of the above, the THz optical properties of the CVD diamond were known with insufficient accuracy. The absorption coefficient was known with an especially low accuracy. We increased the accuracy twenty times thanks to direct calorimetric experiments with high-power NovoFEL radiation (Fig.6). For example, the parameter for the optical quality plate $\alpha = 0.067 \pm 0.003$ cm^{-1} at a wavelength of 130.3 μm [9].

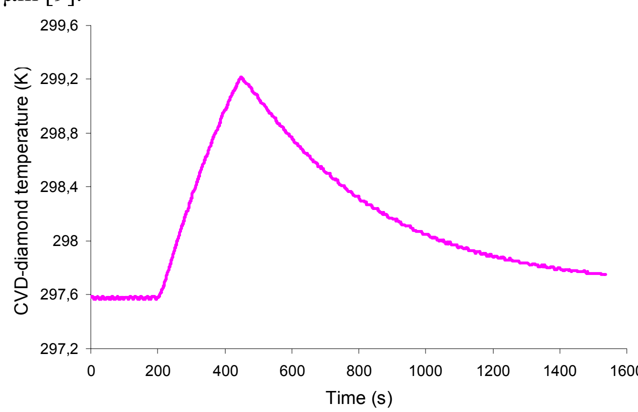

Fig.6. Heating of the CVD-diamond by transmitted THz radiation and its cooling after the radiation blanking.

Many investigations on the NovoFEL were made in the field of semiconductor physics. In particular, various promising compounds were studied both for a room-temperature microbolometer matrix [10] and for a more sensitive helium cooled imaging system [11]. Some experiments of the THz photonic physics (quantum dots, plasmons) are in progress now.

Adjustable sufficiently powerful THz NovoFEL radiation was an ideal instrument in direct experiments for investigations of the optical activity and metamaterial properties of a 2D array of metal-semiconductor microhelices made by using an original technology [12]. A polarization plane rotation of THz radiation of up to 17° at one layer and a negative refraction index of the layer of -0.1 have been obtained.

Specific bright optical radiation was found recently when high-power THz NovoFEL radiation was focused on materials containing calcium. It turned out that it was the Drummond light generated by a treelike CaO structure synthesized as a result of laser ablation (Fig.7). Although the phenomenon has been known since 1825, its adequate theory has not been created yet. It has been shown by optical spectroscopy and He–Ne laser backscattering that the Drummond light of calcium oxide is equilibrium and caused by the transformation of this material at a certain threshold temperature (2000 K) from an analog of an ideal white body (in the optical range) with an emissivity of about 0.1 into an almost ideal black body with an emissivity close to 1 (Fig. 8) [13].

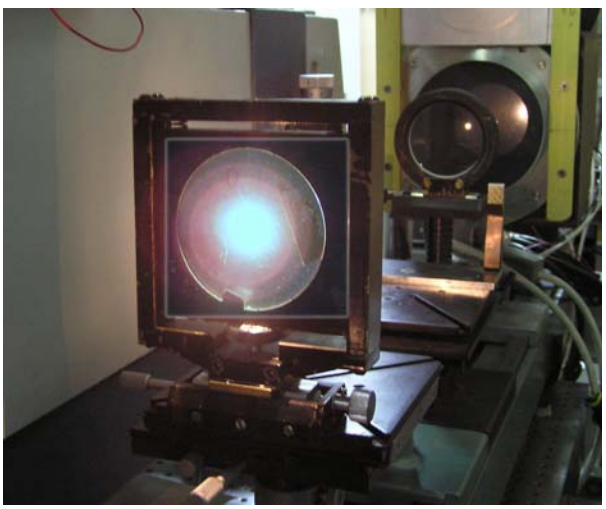

Fig.7. Drummond light of CaO synthesized on the perimeter of 2 mm hole in metallic diaphragm in result of the laser ablation of usual white paper.

We also found a strong optoacoustic effect in water atmospheric vapor. The sound produced by the absorption can be heard without the use of any devices. It is obvious that this effect can be used in sensitive gas spectroscopy.

We plan to use the phenomenon of optical discharge both for gas dynamic investigations and for the synthesis of nanomaterials. We will study the nonlinear interaction of THz radiation with aligned carbon nanotubes of calibrated submillimeter size and the possibility of harmonic generation by the material.

Free electron lasers of the NovoFEL second and third stages of will be used in various photochemical applications.

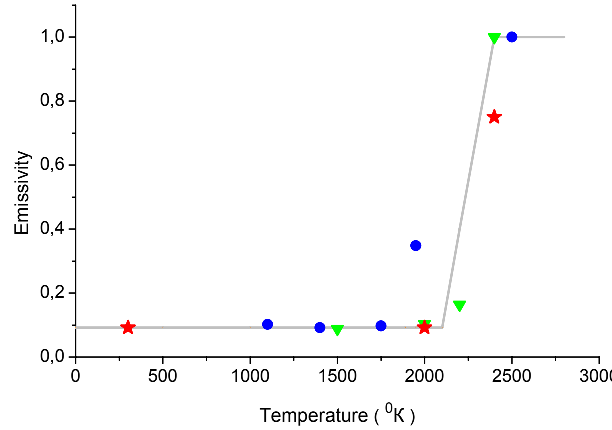

Fig.8. Emissivity of CaO versus its temperature: passive optical spectroscopy (blue and green dots), active HeNe-laser scattering (red dots).

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