Highly sensitive fast Schottky-diode detectors in experiments on Novosibirsk free electron laser

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Abstract

Fast Schottky-diode detectors is used for measurement and optimization of main parameters of Novosibirsk free electron laser (FEL) such as losses in optical resonator, small signal gain, optimal output coupling. Possibility of applying of the device for measurement of coherence time and FEL pulse duration is considered. We plan also to calibrate free electron laser wavelengths by this detector and etalon universal gas laser. High sensitivity of the detector allows apply of it in various user's experiments too.

Introduction

The characteristics of detectors based on Schottky-barrier diodes (SBD) are very attractive for FEL experiments. First, SBD detectors have a unique response time. The time resolution of the devices is usually limited by the electronics behind the diode, since the diode is efficient up to very high frequencies. SBD detectors and mixers operate with output signal in the GHz-range without any problems. Further it should be noted that smallest SBD detectors in contrast to detectors other types really operate at frequencies of incident radiation in infrared, sub-millimeter and millimeter range. Therefore there are many experiments where SBD detector can be used as mixer or nonlinear element. Few such interesting for FEL experiments are described here.

Since physical principle of SBD operation is weakly sensitive to wavelength, these detectors are very wide-band. One detector can easy operates from infrared to millimeter range like slow thermal detectors.

The polarization sensitivity of SBD detectors, which is nearly ideal, is very useful for FEL with linearly polarized radiation. The operating room temperature of SBD and its small size are also convenient.

On the other hand, low frequency "1/f"-noise (flicker noise) which is a well-known shortcoming of SBD detectors, manifests itself only slightly since FEL generate radiation in the form a series of rather short high-frequency pulses. Thus, wide-band fast SBD detectors sensitive to polarization, which are convenient in operation, and FEL are match each other well.

Construction and parameters of SBD detector

The SBD detector can be divided conditionally into two key elements (Fig. 1). The first element is a matrix of formed GaAs-Ti(Au) Schottky diodes with a diameter of 0.5÷1 microns and a cutoff frequency of 7÷10 THz. An ohmic contact of an antenna is realized with one of the diodes of this matrix. The other element is a quasi-optical antenna system for effective input of radiation in the diode. It is known that when the beam patterns of input radiation and antenna coincide, optimal receiving of power takes place.

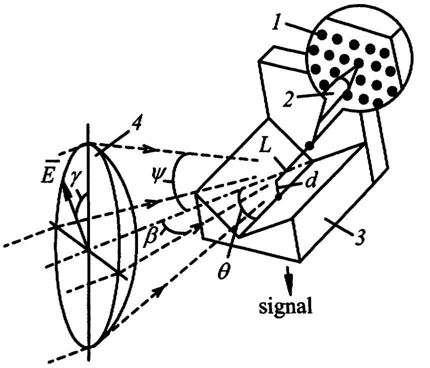

Fig. 1: Scheme of quasi-optical Schottky-barrier detector: 1 – diode Schottky, 2 – antenna, 3 – corner reflector, 4 – focusing lens.

The radiation of a typical FEL is usually in the form of an axially symmetric beam similar to the Gaussian one. Good antenna with a radiation pattern similar to such beam is a single-wire antenna in the 90°corner reflector (Fig. 1) [1]. At any antenna length $L > \lambda$ there is a certain size d of the antenna when it forms a brightly expressed main lobe and a number, approximately equal to $(2d/\lambda)^2$, of small parasitic side lobes 2). Such antenna configurations with the maximum efficiency of the main lobe is called the optimum antennas here. As follows from reciprocity principle in first approximation, the reception efficiency of the antennas is proportional to the main lobe efficiency. The following simple relation of quasi-similarity for optimum antennas was described in [2] (see Fig.1):

$$d/d^{(0)} = \psi_{0.5}^{(0)}/\psi_{0.5} = \beta_{0.5}^{(0)}/\beta_{0.5} = (L/L^{(0)})^{1/2} \qquad (1)$$

where parameters of any optimum antenna can be used as basic parameters with a zero superscript (for example, $L^{(0)} = 4\lambda$, $d^{(0)} = 1.0\lambda$, $2\psi_{0.5}^{(0)} = 14.0°$, $2\beta_{0.5}^{(0)} = 19.5°$). The main experimental parameters of the detector were measured by a universal low-noise gas laser in the modes of HCN and H_2O lasers [3]. As a first approximation, the polarization dependence of the detector signal is described by the function $(\cos\gamma)^2$, where the angle γ is shown in Fig. 1. The volt-watt sensitivity and noise equivalent power (NEP) of the detector at a wavelength of 337 μm are equal to 200 V/W and 0.1 nW/Hz$^{1/2}$ and at a wavelength of 119 μm to 20 V/W and 1 nW/Hz$^{1/2}$, respectively. Antenna of the detector was optimal for 337 μm, but not optimal for 119 μm because of non-linearity of relation (1). Therefore for FEL applications (variable wavelength) we plan to made upgrade of the antenna with variable distance d.

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SBD in FEL experiments

1) Measuring of main Novosibirsk FEL parameters

FELs have large advantage before usual lasers. They have absolutely non-inertial active media. We can fast turn off electron beam and direct measure losses in optical resonator. Then we can measure dependence of radiated power versus different repetition frequencies of the electron pulses (sub-harmonics of light pulses). Using this data one can calculate the main radiation FEL parameters: losses in resonator, unsaturated gain, intensity of saturation, optimal coupling and maximal output power at optimal coupling [4]. These problems can be easy solved by fast Schottky detector and absolute power-meter (Fig.2).

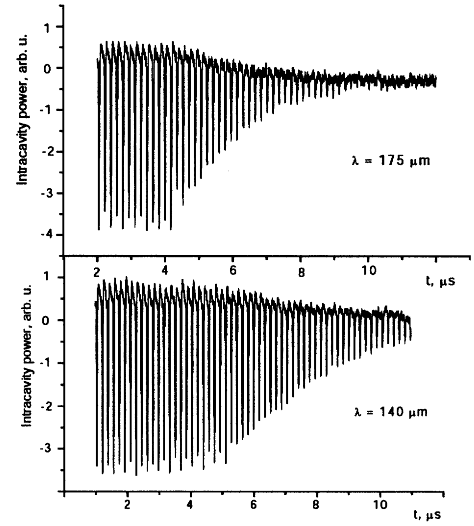

Fig. 2: Signals of output power after switching off the electron beam for different wavelengths of radiation with losses of 5.1% and 8.0% per period accordingly.

2) Measuring of week spontaneous radiation

Illustration of measuring of week spontaneous radiation and wide spectral sensitivity of the Schottky detector is shown in Fig.3. The measurement was made in Korea Atomic Energy Research Institute on compact FEL based on microtron [2].

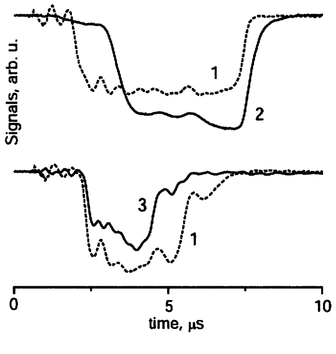

Fig. 3: Typical signals of KAERI FEL radiation in two regimes: 1- electron current, 2 - SBD signal of laser generation at λ = 110 μm , 3 - SBD signal of long-wave (λ > 500 μm) amplified spontaneous emission (laser generation is suppressed).

3) Heterodyne laser calibration of FEL wavelengths

We are going to do absolute wavelength calibration of Novosibirsk FEL by using DBS detector as mixer. We will input in this detector two radiations: one will be FEL radiation, other - radiation of universal high-stability gas laser [3]. As usual we will measure by spectra analyzer the beating signal. Since main wavelengths of the gas lasers are well known with limit accuracy and our gas laser has a record stability parameters, this is most simple, direct and accurate calibration.

4) Determination of time coherence and pulse duration

Radiation of all typical FELs is train of very shot picosecond pulses. Direct measuring of the pulses in sub-millimeter range is practically impossible. Therefore pulse duration is usually determined from some spectral measurement and inverse Fourier transform. But such method is not always right. In common case we determine time coherence only. But very important FEL parameter – pulse duration can be unknown. As consequence the pulse power of FEL radiation will be unknown too. The problem we have in some regimes of our FEL. It can be easy solved by a strongly nonlinear (power non-linearity) SBD detector. Thus Fig.4 illustrates result of simulation when SBD detector is installed in usual Michelson interferometer with one moving mirror and FEL radiation is gauss beam with coherence time in some times less than pulse duration. For obviousness a ratio of pulse length to wavelength is strongly increased in the simulation. Here we propose that output signal in each point of ordinate axis is proportional to P^2 and it is integrated over m =32 pulses. We can see two parts in output signal. Central interfering part is roughly equal to doubled coherence length of light pulse and pedestal is convolution of the envelopes of two pulses. Using pedestal signal and exact dependence of SBD signal versus input wave electric field, we can reconstruct light pulse. Increasing of signal/noise ratio ~ $m^{1/2}$ is not problem in our case too.

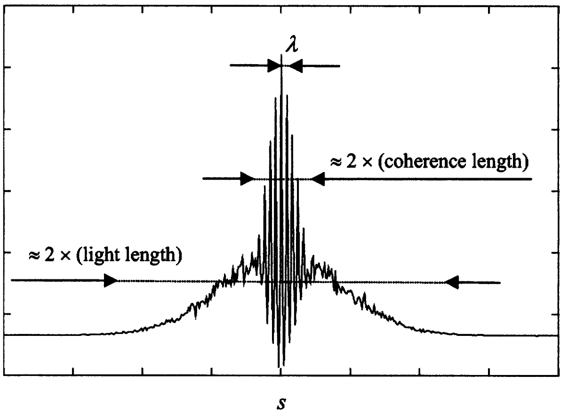

Fig. 4: Simulated signal of SBD detector versus doubled mirror displacement s. Time shift of the light beams is *s/c*.

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