Current status and further improvements of the detector for imaging of explosions

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Abstract

The described detector for imaging of explosions (DIMEX) has been designed for the studies of fast processes (explosions, combustion) at synchrotron radiation (SR) beam. DIMEX has been in operation on the SR beam-line on the VEPP-3 electron ring at Budker INP since 2002. DIMEX is based on a one-coordinate gas ionization chamber filled with a Xe–CO₂ (3:1) mixture at 7 atm and active Frisch-grid made of a Gas Electron Multiplier (GEM). The detector has a spatial resolution of 0.2 mm and dynamic range of ~100, which allows one to achieve a signal measurement precision of a few percent. The future possibility to install a similar detector on the SR beam-line on the VEPP-4 electron ring is discussed and the last version of the detector is described.

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1. Introduction

The detector for imaging of explosions (DIMEX) has been in operation on the synchrotron radiation (SR) beam-line on the VEPP-3 electron ring at Budker INP since 2002 [1–3]. DIMEX is extensively used for the investigation of material properties under very high temperatures and pressures (i.e., during detonation) [5,6]. Such experiments are performed either by measurement of the absorption of SR beam by an exploding sample (direct absorption experiments), or by measurement of the photon flux scattered at small angles from an exploding sample (SAXS experiments). In both types of experiments, DIMEX allows the measurement of one-coordinate image of the X-ray flux emitted by a single electron bunch and interacting with the sample. The detector produces a “movie” of up to 32 such images corresponding to subsequent bunches. Thus, the effective time resolution of the method is determined by the length of electron bunch in the accelerator and is less than 1 ns.

At present DIMEX is operating on the beam-line with a white SR beam from a 2 T wiggler with an average energy of photons around 20 keV (after passing through Be windows (5 mm) and a sample (1 cm of an explosive)) [1]. This low energy imposes a limit of 1 cm on the sample thickness because otherwise absorption in the sample becomes too strong and limited statistics of transmitted photons do not allow achieving necessary measurement precision. A higher energy of SR beam can be obtained on VEPP-4M with a 5-pole 1.3 T wiggler that is now under development. A dedicated simulation study has been performed to estimate the main parameters of DIMEX for the X-ray spectrum on VEPP-4M. The present paper describes the status of DIMEX performance on VEPP-3 and summarizes the results of simulation studies of possible operation on VEPP-4M.

2. DIMEX status on VEPP-3

DIMEX consists of high pressure gas volume with high voltage drift electrode and Gas Electron Multiplier (GEM) separating the conversion region from the induction gap. The detector design is shown schematically in Fig. 1. The X-ray beam enters the detector volume through a 1 mm wide inlet brass slit and 1 mm thick carbon fibre window or 0.2 mm thick beryllium window (in the last version of the detector). Radiation is absorbed in the conversion region between the drift electrode and the GEM top. The depth of the dead zone between the window and the GEM is 3 mm. The depth of the conversion region between the drift electrode and the GEM top is 30 mm. The distance between the drift electrode and the GEM is 1 mm, and the distance between the GEM and the strip board (induction gap) is also 1 mm. Electrons of primary ionization drift towards the GEM, partially penetrate through it and then drift through the induction gap. During the latter phase, there is a charge induced on the strip board. The...
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of photo-electrons, Auger electrons, and fluorescent photons as well.

The energy spectrum of radiation from the 5-pole 1.3 T wiggler
that is now under development for the VEPP-4M ring calculated
by XOP2.0 has its maximum at ~30 keV. At around 50 keV, its
spectral density is about half of the maximum, and the tail
spreads up to 100 keV. More detailed discussion about the
radiation emitted from VEPP-4M can be found in Ref. [4].

The efficiency of a detector with a 1 mm carbon fibre window
detector is filled with a Xe–CO2 (3:1) mixture at 7 atm (absolute)
and works in a sealed mode.

The active region of the strip structure contains 256 strips in
the first detector. In the last version of DIMEX this number has
been increased to 512 strips. The strip pitch is 0.1 mm. The length
of the strips is equal to 30 mm. Each strip is connected to the input
of the integrator chip APC128 [7]. This chip contains 128 channels
with an integrator and a 32-cell analogue pipeline in each channel.
A charge from the integrator can be stored in any of the
pipeline cells. A pipeline can be read out through an analogue
multiplexer with the frequency of 10 MHz.

The spatial resolution of DIMEX is determined mostly by the
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of photo-electrons, Auger electrons, and fluorescent photons as well
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The signal to noise ratio of the detector reaches 100 [3], which
demonstrates the possibility of signal measurement with a
precision of a few percent. The maximal signal is limited by the
space charge accumulation due to slow positive ions in the drift
gap.

The result of one of the direct absorption experiments is shown in
Fig. 2, where the density map of the exploding sample is
reconstructed [5]. The data are reconstructed from the time
evolution of the transmitted signal in one slice, assuming constant
speed of the detonation wave. In the figure one can see the
undistorted sample at Z < -5 mm with a density of ~1.5 g/cm³.
At Z = -5 mm, the density exceeds ~2.0 g/cm³ due to the
detonation and then the sample decays, and the density is
steadily decreasing. The most important observation in this kind
of experiment is the value of density increase behind the
detonation wave, and the exact density profile at the moment of
detonation.

Successful operation of DIMEX during the last 5 years proved
the power of the method of imaging of radiation from a single
electron bunch. However, the detector requires further improve-
ment. For direct absorption experiments, the spatial resolution
has to be improved to 50 μm and better, and the dynamic range
and precision of signal measurement have to be increased. For
both SAXS and direct absorption experiments, a higher frame rate
would be useful, though it is limited by the bunch timing of the
accelerator. Besides, a transition to higher X-ray energies would be
useful for both SAXS and direct absorption experiments. Higher X-
ray energies will allow one to study thicker samples with higher
densities.

3. Prospects of DIMEX with higher energy SR on VEPP-4M

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The efficiency of a detector with a 1 mm carbon fibre window
of a 1.2 g/cm³ density, a 3 mm deep dead zone of gas, and a
30 mm deep sensitive zone is shown in Fig. 3 as a function of X-ray
energy. The efficiency was calculated for a gas mixture of Xe–CO2
(3:1) at an absolute pressure of 7 atm (the calculation was
performed with XOP2.0). Here the efficiency means the
probability of absorption of an X-ray photon in the sensitive
region of the detector.

![Efficiency for spectrum from 5-pole wiggler](image)

Fig. 3. Efficiency as a function of energy. Efficiency and DQE for radiation with realistic spectrum at VEPP-4M shown at E = 30 keV.
An alternative to the gaseous detector can be a solid-state device. Simulations have been performed with a Si detector 1 cm long in the beam direction and 0.3 mm thick in the perpendicular direction. The efficiency for photons with the spectrum from 5-pole 1.3 T wiggler at VEPP-4M in the 1 cm thick Si detector is equal to ~81% while DQE is ~42% due to the fluctuations of deposited energy because of high probability of Compton scattering. The spatial resolution of Si detector is much better than that of the gaseous DIMEX. The simulation results demonstrated FWHM of the LSF of ~20 μm. More detailed discussion of these results can be found in Ref. [4].

4. Conclusions

Several years of experience with DIMEX on the SR beam-line on VEPP-3 have proven the method of imaging of radiation from separate electron bunches to be a very powerful tool. However, in spite of successful application of the detector, further improvement of the method is desirable. The development of the new 5-pole 1.3 T wiggler on VEPP-4M and the construction of the new dedicated SR beam-line will allow increasing the energy and thus the thickness of samples under study. The simulation study performed in the present work demonstrates that the present detector will keep its parameters with a higher energy SR beam on VEPP-4M. The spatial resolution will stay at 0.2 mm (FWHM) and DQE will be around 50%.

Gaseous technology limits the spatial resolution of DIMEX and the maximal X-ray flux that this detector can withstand. Further improvement of both parameters can be achieved with a silicon microstrip detector positioned at a small angle to the beam. The simulation shows that if a beam crosses the Si detector within a 1 cm length, the DQE for the X-ray spectrum from the VEPP-4M wiggler is close to that of the gaseous DIMEX. The spatial resolution, however, can be much better if a proper segmentation is done, because the LSF of the Si detector before the application of any strip readout structure is about 20 μm wide (FWHM).

References