CVD diamond screens for photon beam imaging at PETRA III

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Abstract. PETRA III, the most brilliant storage-ring-based synchrotron radiation source in the world, started its operation in 2009. It features 14 undulator beamlines and will be extended by further 10 beamlines in the PETRA III extension project. During the startup phase of the 14 PETRA III beamlines, fluorescence monitors based on CVD diamond screens have proven to be a very powerful tool for the monitoring of the attenuated undulator beams and for the commissioning of the optical components, e.g. slit systems and monochromators. They served as the essential instrument for the initial setup of the positron beam orbit to align the undulator photon beam along the beamline. The application of CVD diamond screens for the beam imaging at PETRA III beamlines is presented. Images taken during the beam adjustment and the beamline commissioning are shown.

1. Motivation
The PETRA storage ring at DESY has been upgraded to the third generation synchrotron radiation source PETRA III [1]. 14 Undulators produce extremely brilliant synchrotron radiation beams. These beams have to be guided and conditioned for the experiments at the ends of the beamlines. The beamlines are up to 100 m long and the aperture sizes inside the beamlines are in the mm regime.

There is the need for a diagnostic tool that gives a quick and clear feedback while adjusting the beam itself or optical beamline elements in the commissioning phase of each beamline. The CVD diamond screens presented are such a tool for the verification of the beamline alignment and for the surveillance of the beam while commissioning the beamline.

2. CVD Diamond Screens
CVD (Chemical Vapour Deposition) is a deposition process using microwave plasma reactors to deposit polycrystalline diamond out of the gas phase. Defects and impurities enable the fluorescence in the optical regime when exciting the material with X-rays. CVD diamond is highly transparent in the optical regime (when polished) as well as in the x-ray regime (> 5 keV) [2]. Thus, it is possible to use several sequent CVD diamond screens distributed along the beam path simultaneously as shown.
later in this article. Moreover, diamond is radiation hard and has a very high thermal conductivity (5 times as high as copper).

3. Fluorescence

Perfect diamond does not show any fluorescence in the visual regime. Only the defects in natural and artificial diamond create fluorescence in many visible colors, ranging from blue-violet over green down to yellow-orange and red-orange. The most common defects in diamond generating fluorescence are combinations of vacancies and nitrogen.

![Figure 1. Blue fluorescence of a PETRA III CVD diamond fluorescence screen. Image taken at PETRA III beamline P01 in a monochromatic beam at 10 keV.](image)

On a CVD diamond screen in a monochromatic beam, we observed blue light. Blue fluorescence is typically emitted by the N3 centre [3]. It comprises three nitrogen atoms and one vacancy.

On a cooled CVD diamond window in a white beam, we observed orange fluorescence, typically emitted by NV and NV° centres, comprising one nitrogen atom substituting a carbon atom, and a vacancy. See figure 7.

4. Spectral fluorescence yield

The measured fluorescence yield of a tested screen is strongly dependent on the exciting photon energy, as shown in figure 2. It was measured as average fluorescence yield over incident photon flux. The data were measured in a monochromatic beam at beamline P13 [6] at PETRA III. The fluorescence detector was a monochrome CCD camera. The incident photon flux was measured by a calibrated PIN diode.

![Figure 2. Spectral fluorescence yield of one of the CVD diamond screens used at PETRA III, in comparison to the absorption factor of the screen.](image)

5. UHV compatible fluorescent screen units

The gas load of a screen with the geometry described in figure 4 was measured to be less than $10^{-8}$ mbar l/s, which makes them UHV compliant. Residual gas analysis shows that the emitted gas is free of hydrocarbons. The screens have been tested for compliance with clean room class 100, concerning the particle emission.

More than 50 UHV compatible fluorescent screen units of various sizes have been manufactured for the PETRA III beamlines (see figure 3). Each of the 14 frontends features two of these units (see also section 6). It has become a standard to place one unit behind almost every monochromator and every mirror chamber. The direct feedback from the fluorescent screens makes the commissioning and
operation of these optical elements much easier than with intensity monitors, since working with images is much more intuitive.

**Figure 3.** Fluorescent screen units for different beamline sizes. a) DN 40 CF, b) DN 63 CF, c) DN 100 CF

**Figure 4.** PETRA III CVD diamond screens. Diameter: 30 mm, Thickness: 100 µm. Graphitized reticules to indicate the centre of the beamline.

### 6. Application example: Frontend of beamline P09 at PETRA III

Each of the 14 beamlines at PETRA III has a generic frontend, schematically described in figure 5 and in more detail in [4]. The frontend is the first part of the beamline, situated inside the storage ring tunnel. The frontend is about 15 m long and its aperture sizes are in the regime of few mm. There are several fixed apertures and collimators for the absorption of bending magnet radiation. Additionally, there are two slit systems, one defining the beam only in vertical direction, the second defining it in vertical and horizontal direction. Both slit systems can be adjusted in their aperture sizes and positions remotely.

**Figure 5.** Main elements of the PETRA III generic frontend. Each frontend features a laser source and two CVD diamond screens.

**Figure 6.** Alignment of the undulator beam in the prealigned frontend of beamline P09 at PETRA III. Advancing alignment from a) to d).

Before the commissioning of the frontends with an undulator beam, the correct alignment of the apertures and slit systems was verified by monitoring a laser beam that is coupled into the frontend close to its beginning. In this case, the CVD screens serve as simple scattering screens for the laser. After this prealignment, the undulator beam is adjusted to the center of the beamline by tuning the positron orbit in the machine. Thus, the camera images are fed into the storage ring control system TINE [5], so that the operators in the storage ring control room can watch the SR beam on the CVD diamond screens while tuning the positron orbit. With this direct feedback to the operators, steering...
the beam to the foreseen position is very intuitive and thus easy. Since the screens are not cooled, the positron current needs to be reduced to 1 mA while using the screens with a small undulator gap.

Figure 6 shows some example images of an undulator beam alignment. In column a), the undulator gap is widely open and therefore, only the bending magnet radiation is visible. When the undulator gap is being closed, the undulator beam dominates the image, as in column b). Columns c) and d) show the proceeding alignment of the beam to the center of the beamline, indicated by the reticule.

The screens do not show the harmonics of the undulator beam, but mainly the low-energy fraction of the beam. This is due to the high luminosity yield in the lower energy regime (see figure 2). The rectangular shape of the beam on screen #2 is defined by the slit systems. The field of view of the standard optical setup is very large (~ 20 x 30 mm²), in order to image most of the screen. The spatial resolution is about 350 µm, which is sufficient for the intended use.

7. Outlook
For the PETRA III extension project, we are developing cooled fluorescent screen units to overcome the constraint to a positron current of only 1 mA for the white beam commissioning. As a first test, we monitored the fluorescence of a water cooled CVD diamond window (60 µm x Ø6 mm) in a white beam application (see figure 7). On such a window, imaged with a field of view of ~ 6 x 8 mm², we saw a spatial resolution of about 50 µm.

![Figure 7. Orange fluorescence on a cooled CVD diamond window, irradiated by a white beam.](image)

8. Summary and acknowledgements
CVD diamond fluorescent screens have proven to be a powerful tool for the monitoring of synchrotron radiation. They are radiation hard and UHV compatible, highly transparent for x-rays and the fluorescence yield is sufficient to monitor white undulator beams as well as monochromatic beams. The fluorescence yield is strongly dependent on the exciting photon energy, with the highest values at low energies. In total, more than 50 UHV-compatible fluorescent screen units for different beamline diameters have been developed and manufactured. The images, taken by the attached cameras, are available within the machine control system TINE and can be accessed from every computer within the DESY network. The images give direct and intuitive feedback to machine operators and beamline users.

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