TECHNICAL REPORT

The system for delivery of IR laser radiation into high vacuum

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ABSTRACT: The system for insertion of a laser beam into the vacuum chamber of high-energy storage ring is described. The main part of the system is the high-vacuum viewport for the IR radiation, based on ZnSe or GaAs crystals. The design of the viewports is presented.

KEYWORDS: Instrumentation for particle accelerators and storage rings - high energy (linear accelerators, synchrotrons); Instrumentation for particle accelerators and storage rings - low energy (linear accelerators, cyclotrons, electrostatic accelerators)

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1 Introduction

In experiments at $e^+ e^-$ colliders the high accuracy determination of the beam energy is crucial for a lot of studies. The beam energy below 2 GeV can be precisely measured with the calorimetric method based on Compton backscattering of monochromatic CO$_2$(CO) laser radiation on the beam (CBS method) [1].

CBS of laser light on electron beams is a well known method of generation of quasimonochromatic energetic photon beams. Let us consider the Compton scattering process in a case when the angle $\alpha$ between initial particles is equal to $\pi$ and their energies are $\omega_0 \ll m_e \ll E$. Here $\omega_0$ and $E$ are the energies of the initial photon and electron, respectively. The back-scattered photons have the maximal energy, and the energy spectrum of the scattered photons has a sharp edge at the maximal energy:

$$\omega_{\text{max}} = \frac{E^2}{E + m_e^2/4\omega_0}. \quad (1.1)$$

If one measures $\omega_{\text{max}}$, then the electron energy can be calculated:

$$E = \frac{\omega_{\text{max}}}{2}\left[1 + \sqrt{1 + \frac{m_e^2}{\omega_0 \omega_{\text{max}}}}\right]. \quad (1.2)$$

The measurement procedure is as follows. The laser light is put in collision with the electron or positron beams, and the energy of the back-scattered photons is precisely measured using the High Purity Germanium (HPGe) detector with ultra-high energy resolution about $10^{-3}$. HPGe detector can measure the $\gamma$-quanta energy below 10 MeV, so the backscattered photons should have energy $\omega_{\text{max}} < 10$ MeV. For the electron beam energy $E < 2$ GeV CO$_2$ and CO lasers provide initial photons which satisfy requirement at $\omega_{\text{max}}$. The maximal energy of the scattered photons is determined by fitting the abrupt edge in the energy spectrum by the erfc-like function. The beam energy $E$ is calculated from the maximum energy $\omega_{\text{max}}$ using eq. (1.2).

In collider experiments, the CBS method was applied at VEPP-4M [2], the $\tau$-charm factory BEPC-II [3] and at VEPP-2000 [4]. For insertion of the laser beam into the vacuum chambers of...
these colliders the laser-to-vacuum insertion system was developed. As the system is the part of the whole collider vacuum system, the main requirement to it is providing ultrahigh vacuum. It means that it should be possible baking out the system up to 250°C. Here we report the design of the system.

2 Laser-to-vacuum insertion system overview

The delivery of the laser beam into the collider vacuum chamber is performed using the laser-to-vacuum insertion system. The system is the special stainless steel vacuum chamber with an entrance viewport and water cooled copper mirror (figure 1). The system provides ultrahigh vacuum, i.e. pressure of residual gas inside the chamber is less than \(5 \times 10^{-10}\) Torr. The viewport transfers IR laser light into the vacuum and visible synchrotron radiation (SR) light from the vacuum. The output light can be used to monitor the beam position. The copper mirror in the vacuum chamber reflects the light at an angle of 90°. After back-scattering, high energy photons return back to the mirror, pass through it and leave the vacuum chamber.

There are two types of viewports based on GaAs mono-crystal and ZnSe polycrystal plates. Both viewports are manufactured using similar technology and provide:

1. baking out the vacuum system up to 250°C,

2. ultrahigh vacuum,
Figure 2. VacOptix viewport design.

3. transmission spectrum from 0.9 up to 18 µm (GaAs viewport) and from 0.45 to 20 µm (ZnSe viewport).

3 GaAs and ZnSe viewports

There are several methods to make viewports of the specific materials that cannot produce with the traditional method of soldering glass to metal.

The design of the VacOptix windows [5] (technology of VacOptix Company) is based on compression Al gasket between the cap and a crystal plane. The flange and the cap are connected together with welding (figure 2). Maximal temperature of the bake out of this type viewport is 200°C. This technique allows to seal crystalline plates with expanded transmission in all spectral regions including ultraviolet, visible and infrared. It is suitable for making optical assemblies with virtually any glass or crystalline materials, such as CaF$_2$, MgF$_2$, ZnS, ZnSe, without a violation of their penetration properties. The drawback of this product is that it can not be heated more than 200°C. Also, atmospheric pressure and a force applied to the sealing contour create a significant stress to the crystal that can lead to the viewport damage.

Another method of sealing the optical windows is described in U.S. Patent number 4448000 [6]. The apparatus includes two stainless steel flanges, crystal plate and sealing structure with gaskets,
bolts and spring washers. Crystal plate is clamped between a clamp flange and a sealing flange. A lead gasket is located between the sealing knob and one of the sides of the window. To the other side of the window a lead gasket with roughened surface is positioned and a TEFLON gasket is positioned to the clamp flange (figure 3). A constant force is provided for pushing the clamp flange toward the window and the sealing flange, thereby producing a seal between them. In order to limit the pushing force and distribute it uniformly over the window surface the spring washers between a cap of bolts and the clamp flange is used. This method of sealing provide a long-term operation at a temperature up to 275°C. The window is formed from alkali halide materials NaCl, KCl, KBr. The penetration properties of the materials do not change in this assembly. The drawbacks of this design are its complexity, the gaps between the connected parts of the assembly, usage of different types of seals, need of special preparation of the flanges and seals surfaces.

Figure 3. Patent US 4448000 viewport design.
The general drawback of the methods described above is unwanted pressure of assembly parts on the surface of the fragile mono and polycrystalline materials. The method and product reported here prevents this disadvantage and has a more simple structure capable of operating in a UHV systems.

The technique of high vacuum optical viewports manufacture by soldering of quartz window to titanium ring, became the basis for the method of making infrared high vacuum viewports. Manufacture of a viewport includes several stages. First a titanium adaptor ring is brazed with PSr72 alloy (Cu - 28%, Ag - 72%) to the stainless steel ring. Then a quartz plate is brazed with pure soft lead to a titanium ring in a vacuum oven at a temperature of 600$^\circ$C. Lead wets the surfaces of titanium and quartz, and provide the vacuum-tight junction. Due its high linear expansion coefficient the lead compensate for the difference of the plate and titanium ring thermal expansion. This method of sealing provides multiple baking out and long term operation of the viewports at a temperature up to 275$^\circ$C, that is necessary for reaching a residual gas pressure less than $5 \times 10^{-10}$ Torr in the ultra high vacuum equipment. At last the stainless steel ring is welded to the CF flange.

The viewport design is shown in figure 4. It includes a 304 L steel DN63 conflat flange and a GaAs or ZnSe crystal plate with a diameter of 50.8 mm and a thickness of 3 mm or 8 mm respectively. The flat design of the viewport (thikness is less or equal to 25 mm) allows to use the viewports in the limited space of physical equipment.

At a temperature of soldering the morphological changes of ZnSe or GaAs crystal occur. The evaporating substances of the crystal are depositing on its surfaces, impair wettability and this preclude a reliable vacuum-tight junction. To avoid evaporation of GaAs or ZnSe substance from the plates during brazing, they are covered with a 0.6 $\mu$m SiO$_2$ film using gas-phase deposition [7]. This film provide good adhesion of crystal plate with lead solder and allow to obtain reliable junction.

Using described technique the high-vacuum IR windows based on ZnSe and GaAs crystal plates were brazed to the metal for the first time. The successful brazing, which lead to the vacuum-tight junction, became possible after deposition of Si-oxide on the crystals surfaces.

The transmission spectra of the plate before and after covering are shown in figure 5. The transmission of GaAs plate increases from 55 to 60% at the CO$_2$ laser wavelength $\lambda = 10.6 \mu$m and from 20 to 35% at $\lambda = 1 \mu$m. In case of ZnSe plate the transmissin at $\lambda = 10.6 \mu$m decreases from 75 to 62%, but it turned out to be comparable with transmittance of GaAs plate. The advantage of
ZnSe viewport is that it is transparent for the visible part of SR light. This makes the beam position monitoring more convenient.

Actually the viewports were used for delivery of laser beams with the power less than 50 W. No changes of optical properties or damages of the windows were observed.

The viewports were tested at vacuum stand with pressure less than $10^{-8}$ Torr. The tests have included several bakings out at 250°C for 8 hours. The temperature was raised and lowered at the rate of 80°C per hour. After the baking, the air-tightness tests of viewports with sensitivity better than $10^{-10}$ mbar-litre/s were performed. These studies have demonstrated that after numerous bakings the viewports have good vacuum properties. Both GaAs and ZnSe viewports were used at the vacuum systems at storage rings and after backing out at 250°C during 24 hours the pressure $2 \times 10^{-10}$ Torr was obtained.

4 Copper mirror

Copper mirror is the unit that includes the mirror itself and the water colling system. The mirror is a copper disc with a diameter of 80 mm and a thickness of 6 mm. To prevent adsorption of residual gas molecules on the mirror surface, it is covered with a 0.5 µm thick gold layer. The mirror is brazed to the cylindrical stainless steel chamber (figure 6). Note that the copper mirror protects the viewport against high power synchrotron radiation due to low reflectivity of high energy photons (less than 1%) from a metallic surface. Synchrotron radiation (SR) photons heat the mirror. The extraction of heat is provided by water, that come into the chamber and go out of it through the tubes with a diameter of 6 mm. Cooling capacity of this system is about 400 W. This assembly is connected to DN100 conflat flange with welding tubes with a diameter of 26 mm. The tubes of the water cooling system are situated inside them.
The source of SR is collider bending magnet. The maximal actual power of SR which reaches the mirror is 200 W (at BEPC-II). During the usage of mirrors at BEPC-II and VEPP-2000 colliders, we have not observed any affecting on their surfaces.

The unit is mounted to the support (figure 7) and can be turned by bending the flexible bellows through screwing of four bolts, so the angle between the mirror and the laser beam can be adjusted as
needed with accuracy of 1 mrad. Actually, after installation of the laser-to-vacuum insertion system the mirror is adjusted only once and fixed in this position [1]. The precise vertical and horizontal angular alignment of the laser beam during experiment is done by the special mirrors of the optical system mounted at the step motors.

5 Conclusion

The vacuum system for injection of laser beam in accelerator vacuum chamber was designed. The system provides insertion of the light with wavelength in the range from 0.45 to 20 µm. The system is used for calorimetric measurement of the VEPP-2000, VEPP-4M, BEPC-II colliders beams energy using CBS method. After installation of the system at colliders and backing out at 250°C during 24 hours the pressure of about $10^{-10}$ Torr was obtained.

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References

[1] M.N. Achasov and N. Yu. Muchnoi, Beam energy determination in experiments at electron-positron colliders, in proceedings of International Conference on Instrumentation for Colliding Beam Physics, February 24 – March 1, 2014, Novosibirsk, Russia, 2014 JINST 9 C06011 [arXiv:1404.2094].

[2] V.E. Blinov, A.V. Bogomyagkov, N. Yu. Muchnoi, S.A. Nikitin, I.B. Nikolaev, A.G. Shamov et al., Review of beam energy measurements at VEPP-4M collider: KEDR/VEPP-4M, in proceedings of International Conference on instrumentation for colliding beam physics, February 28 – March 5, 2008 Novosibirsk, Russia, Nucl. Instrum. Meth. A 598 (2009) 23.

[3] E.V. Abakumova et al., The Beam energy measurement system for the Beijing electron-positron collider, Nucl. Instrum. Meth. A 659 (2011) 21 [arXiv:1109.5771].

[4] E.V. Abakumova et al., A system of beam energy measurement based on the Compton backscattered laser photons for the VEPP-2000 electron-positron collider, Nucl. Instrum. Meth. A 744 (2014) 35 [arXiv:1310.7764].

[5] Caburn MDC catalog. Viewports and glass components, http://www.caburn.co.uk.

[6] High temperature ultra-high vacuum infrared window seal US Patent Issue on May 15, 1984, US Patent 4448000.

[7] F.N. Dultsev, L.A. Nenasheva and L.L. Vasilyeva, Irregular surface and porous structure of SiO2 films deposited at low temperature and low pressure, J. Electrochem. Soc. 145 (1998) 2569.