Vacuum coupling of photo multiplier tube with monochromator for improved monitoring of VUV emission from Aditya tokamak

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UV sensitive solar blind photo multiplier tube (PMT) attached on the exit slit of the VUV monochromators through a vacuum interface of MgF$_2$ window are, generally, used for detection of emissions of wavelength larger than 2000 Å. However, using windows in front of PMTs always remains a concern from the point of view of detection of weak radiations and also for monitoring the radiations having wavelength lower than 2000 Å due to absorption by air. In the present paper, a technique is presented to monitor spectral emissions from Aditya tokamak plasma in vacuum ultraviolet (VUV) wavelength range down to 1150 Å using a solar blind UV sensitive photo multiplier tube, which is kept inside a vacuum cavity and directly coupled with exit slit of the monochromator and hence avoiding any window interface between monochromator and detector. This technique enables us to improve the detection of VUV radiation in Aditya tokamak, as the VUV photons reaching to detector increase in number due to the absence of any vacuum interface. The comparison of results obtained with this technique with other window based techniques, is also presented.

Keywords: Vacuum ultraviolet emission, Photo multiplier tube, VUV monochromator, Aditya tokamak

I Introduction
Impurity contamination in core plasma of tokamak leads to the confinement degradation through the radiation cooling, as well as fuel dilution due to the presence of fully ionized low Z impurities. Spectroscopic diagnostic plays a major role to understand the impurity behaviour inside the high temperature plasma. With very high temperatures (~ few keV) in the core region of present day tokamaks, plasma impurities mainly radiate in the X-ray and vacuum ultraviolet (VUV) wavelength range since impurity ions undergo multiple ionizations at higher plasma temperatures. To avoid absorption in air, the VUV emission measurements need to be made in vacuum and the conventional diagnostic equipments are either normal or grazing incidence VUV spectrometer depending upon the wavelength range of interest. Depending upon the required time resolution of the measurements charge couple devices (CCD) or PMTs are used as detectors. When higher time resolution is required (< ms), VUV spectrometer is usually operated in the monochromator mode at a pre-selected wavelength with detectors like an electron multiplier tube (EMT) or a photo multiplier tube (PMT) directly coupled to its exit slit, especially for the wavelengths lower than 2000 Å. The PMTs are easier to handle as the EMT does not have any envelope with high vacuum and are vulnerable to contaminations, which causes the decrease of its operational life and increase of noise due to the absorbed moisture. The conventional way of using PMT detectors is to couple it with a scintillator coated window for VUV detection. The scintillator coated window converts the VUV radiation into radiation in visible wavelength range, detectable by the PMTs and also acts as a vacuum interface. However, regular replacement of scintillator window for avoiding the gradual deterioration of conversion efficiency from VUV to visible light necessitates annoying frequent opening of the whole system. To detect strong emissions of wavelength > 2000 Å, UV sensitive solar blind PMT is also used. In this case, the UV sensitive solar blind PMT is coupled to the exit slit of monochromator through a vacuum interface of MgF$_2$ window; however, detection of less intense emission below 2000 Å is difficult with this system.

In the present paper, a new design technique is described on the coupling of the PMT detection system with VUV monochromator in vacuum, i.e. without using any extra window in front of the PMT for vacuum interface. This technique enabled us to
detect the VUV emission down to 1150 Å from Aditya tokamak plasma.

2 Space Resolved VUV Spectroscopy System in Aditya

Space resolved VUV spectroscopy system in Aditya tokamak consists of one meter normal incidence spectrometer and a gold coated flat scanning mirror to scan the plasma along the vertical direction on shot by shot basis. An image intensified charge couple device (ICCD) camera or an UV sensitive solar blind PMT are used as the detector. Schematic view of the system is shown in Fig. 1. Spectrometer (Acton, Model VM-150) has a ruled plane grating of 1200 grooves/mm having ruled size of 102 x 102 mm$^2$ and blazed at 1500 Å. The reciprocal linear dispersion is nominal 8.3 Å/mm and all optical surfaces, i.e. grating, collimating and focusing mirrors, are coated with Al and MgF$_2$. The spectrometer gives the spectral resolution (full width at half maxima) of 0.74 Å at 1623 Å with 100 µm entrance slit. The wavelength coverage is limited down to 1150 Å. The VUV spectroscopy system is evacuated upto 3.5x10$^{-6}$ mbar during its operation.

Figure 2 shows the survey spectra from the central chord of Aditya tokamak plasmas recorded with a VUV-enhanced ICCD detector (Princeton Instruments Inc. Model IVUV-1024MG-E) sensitive in the wavelength range 1200-6000 Å. Spectra in the wavelength range 1150-3000 Å have been obtained on shot to shot basis from several discharges as the spectrometer can cover ~150 Å in one frame when set for a typical central wavelength. Many strong VUV spectral lines from highly ionized N, C and O have been detected. Spectral lines from highest ionization stages, e.g., He-like carbon (C V) at 2271 and 2277 Å and oxygen (O VII) at 1623 Å are identified in this wavelength range. We are able to observe and identify lines up to 1150 Å with the ICCD detector.

Since the ICCD camera has very poor temporal resolution compared to the PMTs for recording the temporal evolution of a particular VUV spectral line radiation, we used an UV sensitive solar blind PMT (Hamamatsu model R1416 with Cs-Te cathode) as the detector. In the initial phase of spectrometer operation, this PMT was coupled to exit slit of the spectrometer through an MgF$_2$ window acted as vacuum interface between monochromator and detector as shown in details in the inset of Fig. 1. To isolate the PMT electrically from the spectrometer which is connected electrically to the tokamak vessel, an electrical insulator made up of teflon is placed between the spectrometer and the PMT, which results in an air filled gap of 6 mm between PMT window and MgF$_2$ vacuum interface. This restricts the detection of UV radiation below 2500 Å because of the presence of oxygen molecule in the air in the gap and also makes the detection of the less intense UV radiation difficult. The oxygen molecules are known to absorb the UV radiation below 2500 Å appreciably because of their high absorption cross-section in this range. Along with that, transmittivity of MgF$_2$ window falls sharply at wavelengths lower than of 2000 Å. Hence, with this arrangement, we could not be able to observe any spectral line below 2000 Å from the similar Aditya tokamak discharges, whereas spectral lines down to 1150 Å are observed using the ICCD camera. Figure 3 shows the attempted measurement of time evolution of two VUV spectral lines, one of O VII at 1623 Å and another of C V at 2277 Å emanated from two similar Aditya tokamak discharges using the above-mentioned arrangement. The line-averaged electron density is ~ 1.8x10$^{13}$ cm$^{-3}$ as measured by microwave interferometer and plasma current is ~ 74 kA during the steady state phases of both the discharges. Figure 3 clearly shows that the spectral line of O VII at 1623 Å could not be detected using the above mentioned method with highest possible voltage applied to the PMT and with maximum gain.
However, the detector could easily monitor the spectral line of C V at 2277 Å. The non-observance of the O VII at 1623 Å spectral line may be due to the absorption of this spectral line by O₂ molecule present in the air gap between PMT window and MgF₂ vacuum interface along with the fall of MgF₂ transmittivity below 2000 Å. The absorption cross-section of O₂ molecule is very large ($10^{-18}$ cm$^2$ at 1600 Å) as compared to $10^{-23}$ cm$^2$ at 2300 Å. The 6 mm air column present in between MgF₂ vacuum interface and PMT window absorbs ~ 50% of radiation of the O VII at 1623 Å. In Addition to that, percentage transmittance of MgF₂ window becomes 62% at 1623 Å. Hence, combination of air gap and the MgF₂ window obstruct the radiation at 1623 Å almost completely to be detected by the PMT.

To overcome this hindrance, we connected the PMT with VUV monochromator directly without the MgF₂ vacuum interface. We kept the PMT inside the vacuum and electrical leads are connected with PMT through a vacuum feed through, hence avoiding the MgF₂ vacuum interface and the presence of air in between vacuum interface and PMT completely.

### 3 Details on New Coupling of PMT to VUV Monochromator and its Performance

Detailed design of the new coupling scheme of the PMT is shown in Fig. 4 schematically. PMT housing is a cylindrical cavity made of aluminium. A 14 pin electrical feed through has been used to power the voltage divider network of the PMT and to bring out the output signal. Vacuum feed through is installed at center of the radial base plate using elastomer O-ring. PMT socket has been mounted on the base plate inside the cavity using two aluminium rods as shown in Fig. 4. All electrical connections coming out from socket have been soldered on vacuum side connector of electrical feed through. The PMT has been firmly supported to align optically with the exit slit of the monochromator using teflon rings, whose depth is equal to the gap between PMT and inner surface of cavity, as shown in Fig. 4. Many holes have been made through the teflon ring to pump out the cavity. The complete assembly was leak tested for vacuum up to $10^{-7}$ mbar. This PMT housing has been installed on the exit slit of the spectrometer using O-ring through an electrical insulator. After that, we have successfully evacuated the complete VUV spectrometer system with this new PMT housing attached up to the standard required for the normal operation of the system during tokamak discharge.

With this new setup, the O VII and C V spectral lines at 1623 Å and 2277 Å have been measured, respectively and the results are shown in Fig. 5. We applied the same voltage to the PMT with similar amplifier gain ($\times 5$) as we did for the measurements as shown in Fig. 3. The major plasma parameters, such as electron density and plasma current are also similar to the earlier set of discharges. With this arrangement, we could observe the O VII spectral line at 1623 Å. Figure 5 shows the temporal evolution of O VII and C V spectral lines at 1623 Å and 2277 Å, respectively. As we have removed the MgF₂ window and the air...
gap in the new arrangement, wavelengths below 2000 Å are now comfortably detectable due to the increase of photon in this wavelength range falling on the detector without any loss by air absorption or by the MgF$_2$ window. This definitely indicates the major improvement of detection of VUV radiations from such lower wavelengths. The C V radiation at 2271 Å should not be very much dependent on the presence and absence of 6 mm gap and MgF$_2$ window. However, the lower values of C V radiation at 2277 Å observed in the later discharges is due to lower carbon influx and less plasma temperatures in the discharges as shown in Figure 5. Lower values of C$^+$ emission at 5696 Å (shown in Figs. 3(c) and 5(c)) in the visible range in the later set of discharges indicates lower amount of carbon impurity entering into the plasma$^{10}$. Furthermore, the electron temperature, $T_e$, as measured by soft X-ray diagnostics, is $\sim$ 250 eV for the discharges as shown in Fig 5, whereas $T_e$ is $\sim$ 325 eV for the discharges shown in Fig. 3, which may be the reason for observing larger C V emission from earlier set of discharges shown in Fig. 3. To demonstrate the capability of the new arrangement for measurements of spectral lines down to $\sim$ 1150 Å in the VUV range as observed with the ICCD camera, we attempted to measure L$_a$ at 1215 Å with the new arrangement. The L$_a$ at 1215 Å has been successfully monitored as shown in Fig. 6(b), which was not possible with the old arrangement of PMT being kept out of vacuum and using a MgF$_2$ window. Figure 6(a) shows the plasma current and loop voltage for the same discharge in which the L$_a$ at 1215 Å is measured.

4 Conclusions
Coupling of solar blind PMT with VUV monochromator in vacuum enables us to successfully monitor the VUV radiation lower than 2000 Å from Aditya tokamak, which is not possible when the PMT is coupled to monochromator through a vacuum interface of MgF$_2$ window. In the new coupling technique, PMT is kept inside a vacuum cavity and electrical lead connected through the electrical vacuum feed through. Wavelengths down to 1150 Å in VUV range have been recorded using this technique.

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References