Measurement and calculation of scattered Synchrotron Radiation processes at the KARA visible light beamline

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Measurement and calculation of scattered Synchrotron Radiation processes at the KARA visible light beamline

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Abstract. At KARA a visible light diagnostic beamline is in use to analyse the stored electron beam. Synchrotron light is deflected 90 degrees upwards by a cooled copper mirror, passes through a Quartz UHV window and is then reflected back into the horizontal plane but sideways through a hole in the wall to the diagnostics. Based on experience from similar Infrared beamlines no significant radiation (doserates larger than 0.5μSv/hr) was expected. Nevertheless, a higher radiation level exists but can be shielded with 0.3mm Aluminium foil or 2.0mm of Pyrex reducing the rate to an acceptable level. The presence of the radiation led to further investigation by experiment and calculation. A custom setup using a silicon drift detector (SDD) for energy dispersive spectroscopy showed the radiation to be predominantly Copper K-alpha and is confirmed by FLUKA and other calculations of the scattered Synchrotron radiation.

1. Introduction

At KARA a visible light diagnostic beamline has been developed [1] to characterise the stored electron beam. The optics is similar to many other Infrared [2] and UV beamlines [3] with a chicane formed by two mirrors and a vacuum window in between. Based on experience with such beamlines no significant radiation is expected (doserates larger than the allowed 0.5μSv/hr). Surprisingly a higher radiation level was seen but could be shielded with 0.3mm Aluminium foil or 2mm of Pyrex reducing the rate to an acceptable level. The high dose was also removed by closing the beam shutter indicating that it was not due to an electron loss bremmstrahlung background. The presence of this radiation, and also uncertainty as to its exact nature and origin, led to further investigation by both experiment and calculation. Higher energy Synchrotron radiation was found to be responsible. The synchrotron radiation is scattered by the first mirror passes through the Quartz window and ionizes the copper of the second mirror resulting in a large Cu K-Alpha, Beta fluorescence. The findings give a better understanding of the radiation process which might happen at comparable beamlines (THz, IR, visible light) and other beamlines with few optical components. A picture and schematic of the visible light diagnostic port is shown in Figure 1.

2. Experimental Set-up

The Synchrotron light is captured by a water cooled plane mirror which is then deflected upwards through a 5mm thick Quartz window isolating the vacuum. The transmitted light is then deflected sideways horizontally through a hole in the ring wall to the diagnostics by a second mirror. The second mirror is a polished parabolic mirror. Both mirrors are made from copper and are coated with thin 30µm reflecting Aluminium coatings.

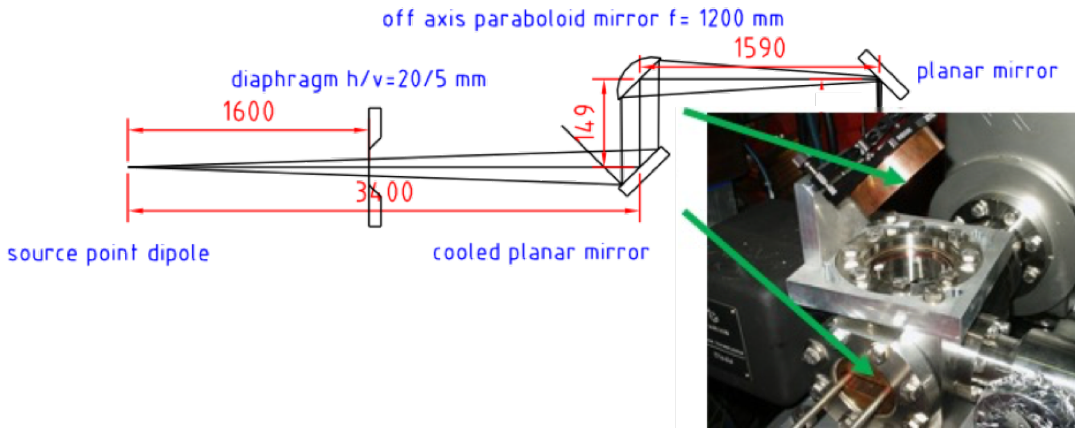

Figure 1. Schematic and picture of Visble Light Diagnostic Port showing Aluminium coated water cooled planar and off axis copper parabolic mirrors.

3. Experiment

The fluorescence spectrum detected from the off axis paraboloid is shown in Figure 2 as the red curve. To high energies a large broad background is seen. The black line is the result of a calculation and is further discussed along with the fluorescence in the results section.

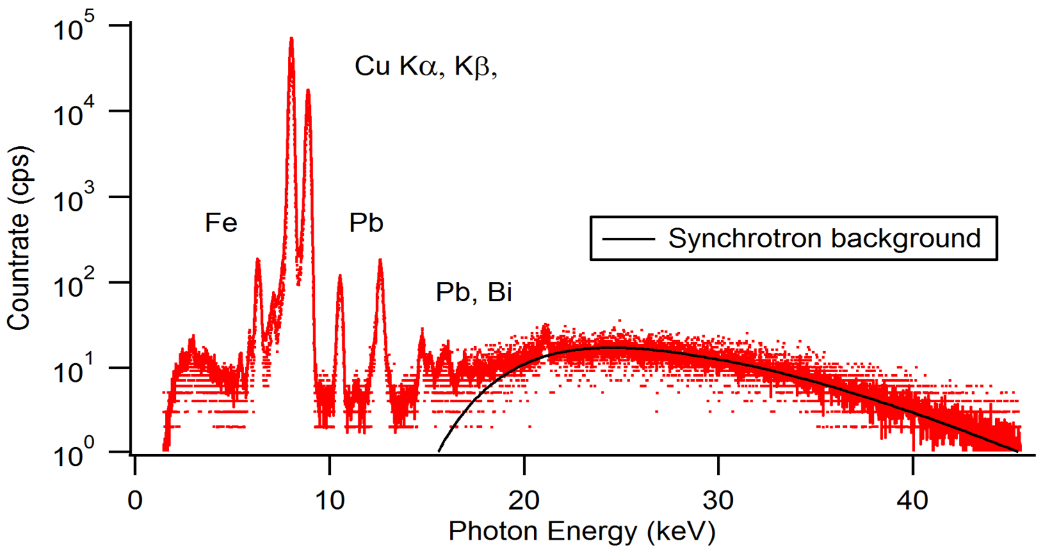

Figure 2. Fluoescence spectrum showing the dominant Copper K-Alpha fluorescence with weak components of Lead, Iron and Bismuth and the high energy scattered Synchrotron Radiation background. The black line is the calculated background described in the Results section.

In addition to the fluorescence spectrum (Silicon Drift Detector-SDD, KETEK) the radiation was measured using UMO and Tol-F dosimeters (Berthold) and a calibrated Photodiode (Hamamatsu). The combination of the detectors with thin foil attenuation measurements identified the higher dose as originating from scattered Synchrotron radiation. Additional secondary fluorescence and scattering of radiation into the various detectors was avoided by use of an Aluminium profile frame and plastic holders. The SDD output was further treated using a digital signal processor and associated software (XIA).

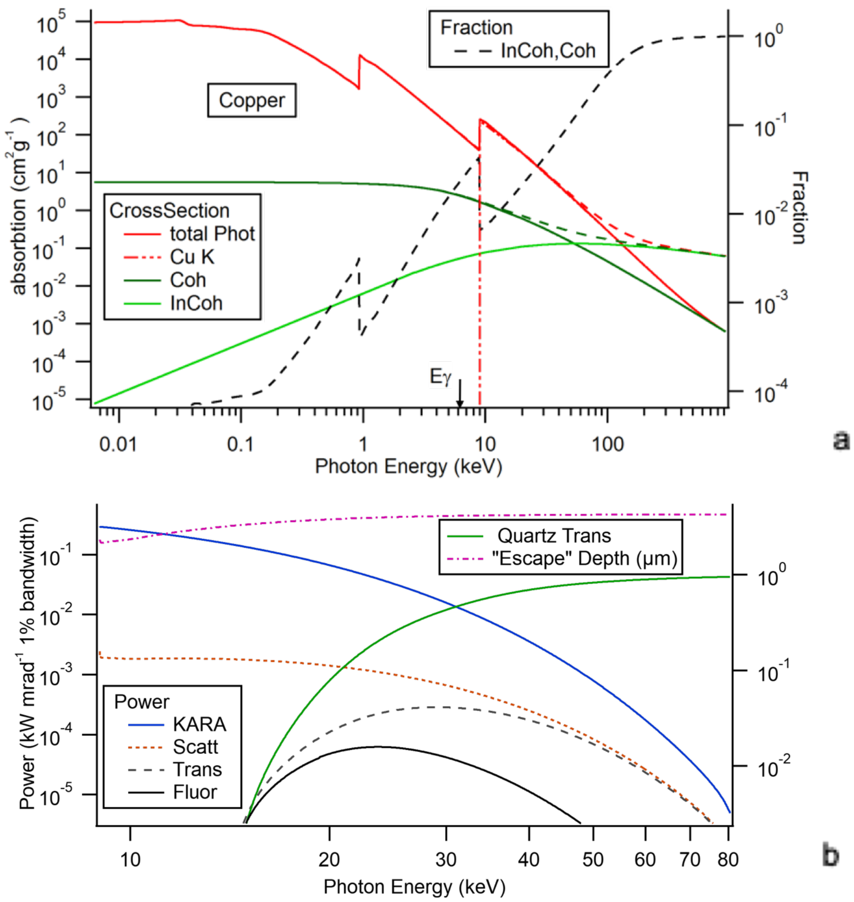

Figure 3. Fig. 3a shows the various cross sections as a functtion of Photon Energy and the fraction of coherent, incoherent contribution to the total cross section. The Synchrotron power, window transmission, "Escape" Depth and other quantities described in the text are shown in Fig. 3b. The black curve shows the power as function of energy that results in Cu K-Alpha fluorescence. The critical energy of the machine 6.243keV at 2.5GeV is shown for guidance in Fig 3a.

4. Results and Discussion

Figure 3 shows the various cross sections [4] and the derived quantities used for calculating the observed radiation dose and the background shown in Figure 2. At low photon energies below 10keV the photoelectric cross section dominates, above this Coherent Rayleigh scattering becomes significant and above 100keV the Incoherent Compton is dominant. Figure 3a also shows the fraction of the 90 degree contributions of the coherent and incoherent scattering to the total cross section. At 10 keV this is of the order of a few percent. Various power quantities as a function of energy together with the transmission of the Quartz window and the "escape" depth of photons in copper are shown in Figure 3b. The "escape" depth arises from the depth integral of the exponentially attenuated photon flux incident on the second mirror together with the attenuation of the resulting fluorescence. Using the above fraction and the transmission of the window the power incident on the second mirror can be calculated. This together with the "escape" depth, Copper K shell ionisation cross section and fluorescence yield gives the power as a function of energy (black curve, Fluor) resulting in the Cu K-Alpha fluorescence. Numerically integrating and using the appropriate solid angles gives the desired dose of 25μSv/hr which is close to the measured 55μSv/hr. From the Figure it is also seen that the high energy scattered photons are responsible for this dose, Any fluorescence from the first mirror is absorbed by the 5mm Quartz window, As mentioned in the introduction a high energy background is also visible in the spectrum. This can be calculated from the transmitted power and coherent, incoherent fraction and the detector response. This is the black line in Figure 2. and is in good agreement with the spectrum.

5. FLUKA-Simulation

The radiation has also been investigated by FLUKA [5] an established Monte-Carlo Programme for simulating radiation. For the calculations the beamline is divided into 3d block sections with assigned properties (vacuum, copper, concrete, etc.). The starting point for the Monte Carlo calculation are a number of photon energies weighted by the Synchrotron radiation spectra of KARA. The photons then scatter randomly and propagate through the above blocks using built in cross sections. For the calculations approximately one million events are modelled. The results of the simulation are shown in Figure 4. The blue curve gives the spectrum of the SR before the first mirror. The orange curve gives the spectrum of the particles scattered from the first mirror. A peak around the Cu-K edge (8 keV) appears plus a continuum at higher energies. The grey curve gives the spectrum behind the window. The window establishes a high pass filter, suppressing nearly all events below 15 keV including the fluorescent radiation from the first mirror. The yellow curve gives the spectra behind the second mirror. Although the incoming radiation is of higher energy, it still produces a peak at the fluorescent edge, which had been confirmed by the experiment. The FLUKA simulation had been rather time consuming (days) and the statistics behind the second mirror and shielding wall allowed only a dose estimate in the 10 μSv/h range. A contour-plot for the dose rate is given in Figure 5.

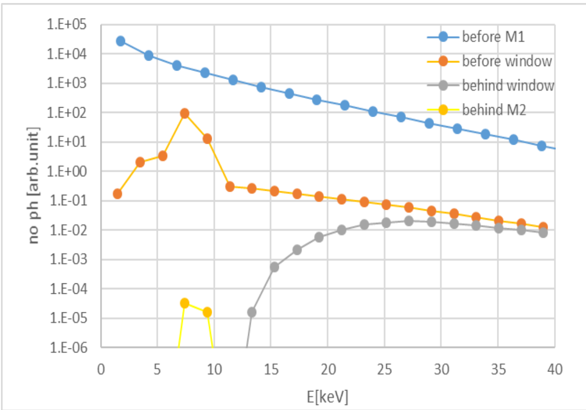

Figure 4. FLUKA Spectra before and behind the 1nd mirror, behind the window and behind the 2nd mirror.

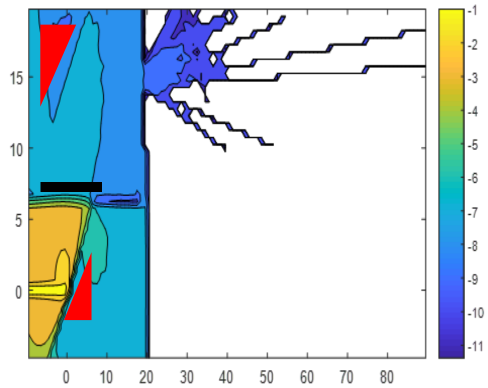

Figure 5. FLUKA contour-plot of dose-rate dose [log 10 Sv].

6. Conclusion

The Copper fluorescence produced at the first mirror is absorbed by the window leaving the high energy Synchrotron radiation to be transmitted which acts as a source for the Cu K-Alpha fluorescence from the second mirror. Use of lower Z materials (Al, Si, SiO2) would result in lower energy fluorescence and a lower dose. The findings give a better understanding of the radiation process which might happen at comparable beamlines (THz, IR, visible light) and other beamlines with few optical components.

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