OXYGEN SCINTILLATION IN THE LCLS*

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Abstract

Oxygen was tested as a replacement for nitrogen in the Gas Detector system in the Linac Coherent Light Source (LCLS) X-ray Free Electron Laser (FEL) at the SLAC National Accelerator Center. The attenuation and pulse-to-pulse intensity monitors for LCLS use nitrogen, but for experiments at the nitrogen K 1S energy of about 410eV this functionality is gone due to energy fluctuations above and below the K-edge. Oxygen was tested as a scintillating gas at 400 eV and 8.3 keV.

INTRODUCTION

In the LCLS X-ray beam, a length of the beam transport line is filled with low pressure nitrogen. One use of the gas is to attenuate the X-ray intensity as needed [1]. The gas pressure in a 4 meter section is controlled at pressures of up to 20 Torr to implement this, and it is useful up to X-ray energies of about 1.5 keV. Additional short sections before and after the attenuator section have independent pressure controls for up to 2 Torr, and are used to monitor the X-ray laser beam intensity. They function by making use of the excitation of the nitrogen molecules by the X-ray beam. As the nitrogen de-excites, a fraction of the energy is emitted in spectral lines in the range 300 to 430 nm, corresponding to both excited and ionized molecular transitions. Some of this light is detected through sapphire beam windows by photomultiplier tubes.

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The beam chamber for these devices contains a series of 4 mm diameter beam apertures with differential pumping between them, to reach the base level at E-8 Torr beyond the device. Ion-pumps, turbo-pumps backed by scroll-pumps and Roots pumps are used.

The nitrogen K-edge occurs at about 410 eV (Fig. 1). When the LCLS is tuned to operate at this energy, the nitrogen gas systems are not useful because their response varies wildly as the beam energy fluctuates within its intrinsic width.

For the occasions when users need X-ray energies in the nitrogen K-edge range, a solution is to use an alternative gas. The practical requirements are that the pumping system can maintain the upstream and downstream base pressures, while delivering a useful range of pressures for the attenuator and detectors (Fig. 2), and that the de-excitation light should be detectable with the present vacuum windows and photomultiplier system.

Light noble gases would be considerably more difficult to pump, and, with the exception of helium, their reported light emission wavelengths are too deep in the ultraviolet. Oxygen is the nearest analogue to nitrogen as far as gas handling and pumping is concerned.

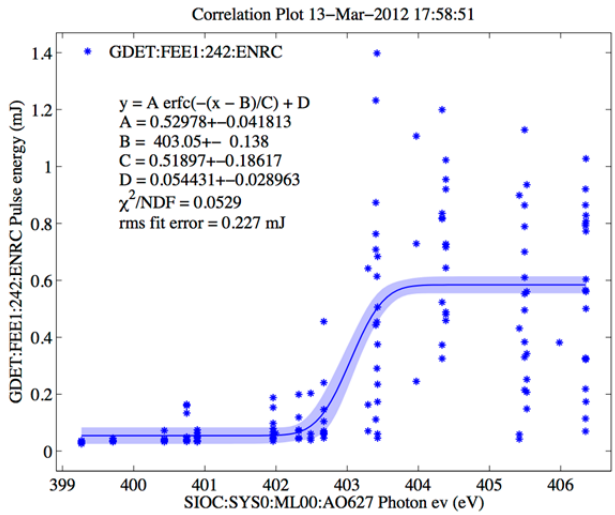

Figure 1: X-ray energy on the horizontal axis, vertical is nitrogen response as a function of the energy fluctuating under and over and spanning the K 1S edge.

THE BEAMLINE AND OXYGEN

Oxygen Concerns

With oxygen, no changes to the pumps are needed, and the switch over from one gas to the other is fairly simple. Since it is used at very low pressures, there is no significant combustion safety issue, except for normal oxygen precautions for the source and regulator. The chemical activity of atomic oxygen and ozone generated in the beam pipe has been considered. Most of it is, of course, intercepted by the walls and aperture plates, and the concentration downstream is too small to be of concern. B4C, which is often used as an absorber for X-rays, is known to be etched by ozone in the presence of strong UV illumination. Based on this, an upper limit on the etching rate on B4C components in the ~10 Torr oxygen environment shows surface loss too small to be significant.

Oxygen Utility

The oxygen K-edge is at 530 eV, and so, used at near 409 eV, its absorption would be relatively low, comparable to that of nitrogen at 1095 eV. This improves resolution, and operability at low pressure, of the controls of the gas system. For example, a pressure of 0.05 Torr used in nitrogen at 415 eV would be matched by 0.6 Torr using oxygen.

* This work was supported by U.S. Department of Energy, Office of Basic Energy Sciences, under Contract DE-AC02-76SF00515

ISBN 978-3-95450-133-5

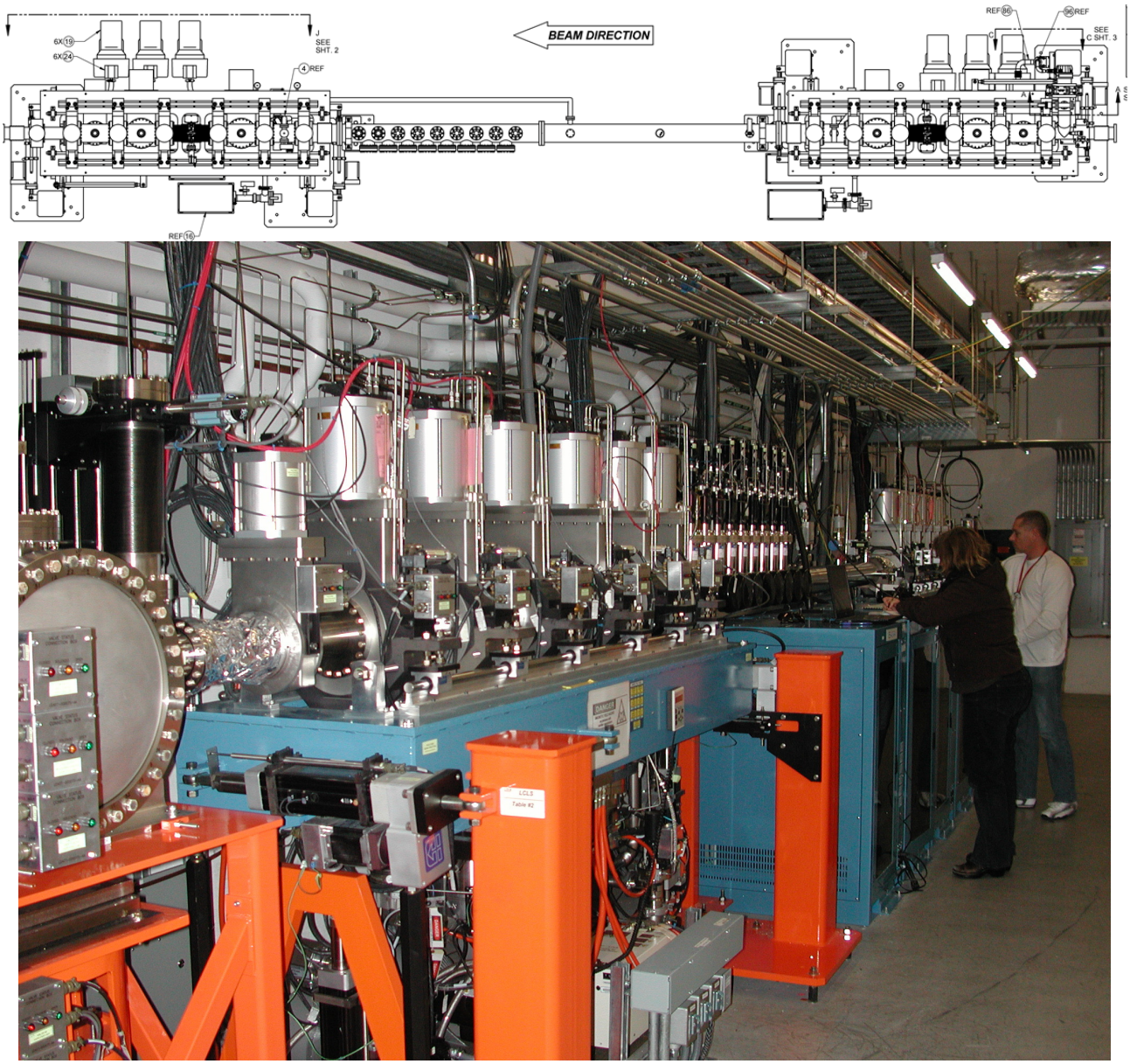

Figure 2: Gas Attenuator installation drawing and photograph. Gas Detector 2 Differential Pumping Assembly is centered, the gas attenuator is above the blue instrumentation and control racks right of center, and the initial Differential Pumping Assembly in the right distance.

Oxygen Literature

On the other hand, the light emission of oxygen is not as well understood as is that of nitrogen. Nitrogen has been studied in detail since, for example, it produces effectively all the atmospheric fluorescence that is used to measure extensive showers from cosmic ray interactions. Oxygen's effect in suppressing the nitrogen fluorescence is also well measured.

A relevant measurement, where gas at near 1 atmosphere was excited by charged particles, and the fluorescence light detected by a photomultiplier tube, reported [2] that the oxygen light emission is approximately 1% of the nitrogen output. However, at low pressures, the de-excitation processes for the different excitation bands change by a large amount from the 1 atmosphere values, and it is not possible to extrapolate. There are some spectra from low pressure oxygen that can be found in the literature. Some of these have evidence of nitrogen contamination. However, there are some reported emission lines in the UV-blue range, extending to longer wavelengths than for nitrogen.

Customizing the System

The wavelength range originally used for the light from nitrogen used optical filters to cut off light at wavelengths longer than about 385 nm. This was done to strongly reduce broadband light that is occasionally encountered

ISBN 978-3-95450-133-5

from coherent emission processes associate with the electron beam far upstream. To accommodate the weak emission from oxygen, the optical filters have been replaced and the pass-band has been extended up to 450 nm. (This also increases the signal from nitrogen.) The occasional effects of coherent light are removed by a timing cut on the pulse profile.

Beam Tests

The use of oxygen has been tested with the X-ray beam. As expected, it was found that gas handling was similar to the use of nitrogen. The largest uncertainty was in the light emission, and signals were indeed detected. The de-excitation time in this environment was much shorter than for nitrogen, with 90 % amplitude reduction in less than 100 nsec. In Fig 3 and 4, pulse profiles from nitrogen and oxygen are illustrated.

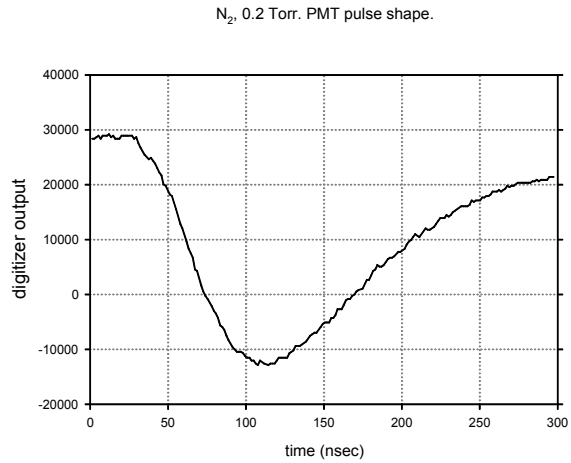

Figure 3: Nitrogen de-excitation time.

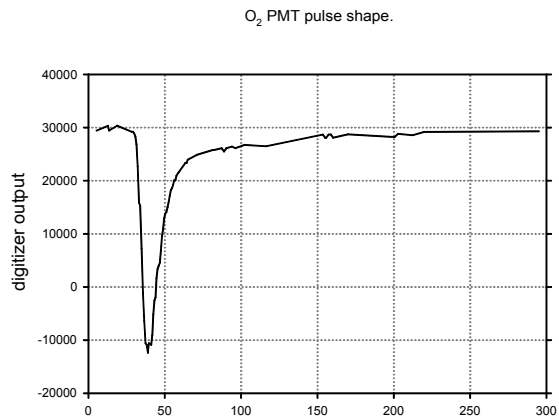

Figure 4: Oxygen de-excitation time.

The hard X-ray operability was tested with 1.5 millijoules at 8.3 keV. Using 2.0 Torr of oxygen, the PMT (photomultiplier tube) high voltages had operational headroom indicating capability at higher energies.

Solenoids surrounding the chambers optimized roughly at the same fields as used with nitrogen.

The pulse amplitude fluctuations were consistent with expected fluctuations of the beam, and photon counting statistics were adequate for the device's normal use as a tuning and monitoring tool. A correlation between signals from two PMTs, measured on the same pulses, showed an RMS spread of 1.0 %, indicating that the beam intensity measurement could be made to 0.5 % on a pulse-by-pulse basis by averaging the two PMT signals.

CONCLUSION

LCLS gas detectors were tested using oxygen at soft X-rays (near the nitrogen K edge) and at hard X-rays (8.3 keV). The most notable difference to nitrogen was in pulse duration and subsequent gating. With oxygen however, the gas detectors were clearly operable as a relative intensity monitor at both energies tested with capability to go to higher energy.

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[2] J. Heintze et al., Nucl. Instr. and Meth. 138 (1976) 641.

ISBN 978-3-95450-133-5