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ABSTRACT.
The JET Tokamak has two LIDAR Thomson Scattering systems, one for measuring the core T_e and n_e profiles and one dedicated to the edge parameters. The LIDAR scheme is unique to JET and is also envisaged for use on ITER. The system's spatial resolution is defined by the convolution product of its components: laser pulse duration, detector response time and digitizer speed. The original multi-alkali photocathode micro channel plate photomultipliers dictated the response time of the system, resulting in a twelve centimeter spatial resolution along the line of sight. In the edge LIDAR system, this is improved by aligning the line of sight with the flux surfaces, thus improving the effective, across flux surfaces, spatial resolution to two centimeters, depending on the plasma configuration. To meet demands for better resolution of the edge gradient, an upgrade to higher quantum efficiency detectors was proposed. Four GaAs photocathode detectors have been procured, two of which surpass expectations. These detectors are shown to have a more than two times higher effective quantum efficiency and their response time is at least twice as fast as the multi-alkali detectors. In combination with a fast digitizer this improves the spatial resolution of the system by a factor of two, down to one centimeter effective, depending on plasma configuration.

1. INTRODUCTION
The LIDAR, Light Detection and Ranging, Thomson Scattering time of flight technique [1] is unique to JET. And is also envisaged for ITER core and possibly inner divertor leg electron temperature and density measurements. The two original JET LIDAR Thomson Scattering systems use Multi-Alkali photocathode Micro Channel Plate (MCP) Photomultipliers and 1 GHz bandwidth digitizers, and have a spatial resolution of 12 cm along the line of sight [1]. The effective spatial resolution is enhanced in the Edge LIDAR diagnostic by making the line of sight close to tangential to the plasma flux surfaces [2]. A special Diagnostic Optimized plasma Configurations (DOC-U) has been designed to further improve on this flux surface alignment. In DOC-U the effective spatial resolution of the system is ~ 2 cm and density gradients are routinely resolved.

In order to resolve non-optimized configurations, the edge LIDAR system has been upgraded with higher quantum efficiency GaAs photocathode detectors, in addition the new detectors turn out to have faster response times [3]. Some edge gradient data has been obtained with these new detectors coupled to a high bandwidth digitizer. A comparison between the old and new system's results is presented.

2. KEY FEATURES OF THE ORIGINAL JET LIDAR THOMSON SCATTERING SYSTEMS
Since the LIDAR system is a back scattering system it is easy to align, and has no electronics or delicate optics near the machine. The LIDAR scheme is also less susceptible to stray light and background radiation. The spatial resolution is the convolution product of three components: laser pulse duration τ_l, detector response time τ_{det} and digitizer response time τ_{dig}. The total system

spatial resolution then is $\Delta_\chi = \frac{c}{2}\tau_{tot} = \frac{c}{2}(\tau_l^2+\tau_{det}^2+\tau_{dig}^2)^{1/2}$ For the JET system τ_l = 300 ps, τ_{dig} = 333 ps, and the Multi-Alkali MCP Photomultiplier Tubes (MCP-PMT) τ_{det} = 650 ps. τ_{tot} is 796 ps, which corresponds to a spatial resolution of approximately 12 cm. In the edge LIDAR system [2] this gives an effective spatial resolution between 2 and 4 cm depending on the plasma configuration and the system line of sight [4].

3. THE UPGRADE

An upgrade was proposed to increase the accuracy of edge spatial profile measurements, taking advantage of developments in photocathode technology. The edge LIDAR system has now been upgraded with higher Quantum Efficiency detectors in order to better resolve the edge gradients of the plasma. In the following sections the properties of these new detectors and the effect of a higher bandwidth digitizer (6 GHz compared to 1 GHz) are investigated.

A) - RESPONSE TIME

To determine the response time of the new detectors they are illuminated with a variable intensity light source, the level is reduced until single pulses, i.e. single photoelectron events, can be seen. The Full Width Half Maximum, FWHM, is a measure for the response time. In figure 1a the results are shown for one of the PMTs (5410), the measurement is done with a 5GHz bandwidth oscilloscope. The response time is found to be: ~ 250 ps, figure 1b, the

bandwidth is then given by: $B = \frac{1}{3 * FWHM}$.

The GaAs detectors are found to be more than twice as fast as the old Multi-Alkali detectors. This greatly improves the potential for increased spatial resolution.

B) - QUANTUM EFFICIENCY AND GAIN

The rationale of the upgrade was to increase the Quantum Efficiency of the detectors to decrease the errors and so improve the resolvability of edge gradients.

The ratio between the number of input photons and number of electrons produced by the photocathode is the Quantum Efficiency QE and is determined directly by shining a calibrated light source on the photocathode and measuring the current on the input side of the MCP. Figure 2 shows the measured QE as a function of input wavelength.

For this diagnostic we are interested in the effective Quantum Efficiency QE_{eff}, because that gives a measure of the number of events seen on the anode for every photoelectron event on the cathode. So, unlike the QE, which incorporates the photocathode only, it incorporates the entire detector. QE_{eff} is defined as the ratio between the QE and the excess noise Factor F. And can be measured by analyzing the signal S_m to noise N ratio with a calibrated input signal. F is noise created by the MCP, independantly of the set gain G_{MCP}. $N^2 = G_{MCP}^2 * F * QE * n * B$, where B is the bandwidth and n is the known input photon flux. The measured signal is $S_m = G_{MCP} * QE * n$.

Then the signal to noise ratio can be measured: $\left(\frac{S_m}{N}\right)^2 = \left(\frac{QE}{F}\right) * \frac{n}{B} = QE_{eff} * \frac{n}{B}$ where the only unknown left is the bandwidth B. The bandwidth is measured by doing the single photoelectron experiments described above. A Signal to noise measurement result and its autocorrelation function are shown in figure 3. From the measurement follows that $QE_{eff} = \frac{(S_m/N_{rms})^2}{n\tau}$ where S_m is the measured output signal, N_{rms} is the standard deviation, n is the photon flux at the detector and t is the system's characteristic time, which is defined as: $\tau = (\pi)\_\tau_{ac}$, with $_{tac}$ the width of the autocorrelation function of the noise [3].

The old Multi-Alkali MCP-PMTs have a QE of 5.2% and F = 1.9, so QE_{eff} = 2.7%. For the new GaAs MCP-PMTs QE has been measured to be higher than 26, table 1 shows all measured QE and QE_{eff}. The QE of MCP tubes 5090 and 5098 is very similar to that of tubes 5405 and 5410. However their QE_{eff} is much lower, this is due to their much higher excess noise level F. Why this is higher is still not entirely clear, but a difference in manufacturing process is likely to be the cause, since the 'bad' detectors are blue enhanced.

The gain is the ratio between the number of input photoelectrons per nanosecond on the MCP and the number of electrons per nanosecond measured at the output anode. The gain curves are shown in figure 4 as function of MCP voltage.

4. IN SITU MEASUREMENTS

A) - WHITE LIGHT SOURCE CALIBRATION

One of the first in situ measurements done with the upgraded system is a white source calibration. A white light source is placed far away in the collection path of the system, the response of the detectors is measured and shown in figure 5.

Tubes 5405 and 5410 show a clear "switch-on spike", an artifact that is caused by light already falling on the photocathode when the tube is gated. This feature is not visible on detectors 5090 and 5098. Instead of switching on and reaching the background light level within 4 ns, they need up to 8 ns to reach equilibrium. However, their response time is just as fast as the other tubes (5405, 5410). In the diagnostic this is not really a problem, since the detectors are switched on approximately 10 ns before the laser pulse reaches the plasma.

With the new detectors the total response time comes down to: $\tau_{tot} \approx 500$ps. This is a 37% improvement on the spatial resolution.

B) - FAST 6 GHZ, 20 GS/S, OSCILLOSCOPE

An Agilent 6 GHz (20 Gs/s) bandwidth oscilloscope was borrowed, to investigate further improvement. The new total response time should theoretically be $\tau_{tot} \approx 396$ ps. This is factor two improvement over the original, Multi-Alkali system. Unfortunately during the period of loan, there were limits in the available power from the JET Neutral Beam heating. This limited the plasma parameters and no really high edge gradient H-mode plasmas were produced. Figure 6 shows the highest gradient results achieved, during the period of loan.

This profile is clearly resolved even with the old system, also shown in this figure is the theoretically maximum achievable resolution. The higher QE of the detectors is visible in the fact that the error bars at high R_{mid}, i.e. low temperature, are smaller.

Using the borrowed 6 GHz (20 Gs/s) oscilloscope a 5.9 cm spatial resolution along the laser line of sight or approximately 1 cm in DOC-U configuration, can be reached. Also this system has been shown to be compatible with the existing hardware.

Table 1: QE and QE_{eff} of the new detectors.

Detector No	5090	5098	5405	5410
QE	26	26	30	27
QEeff	0.6	0.9	6.5	6.0

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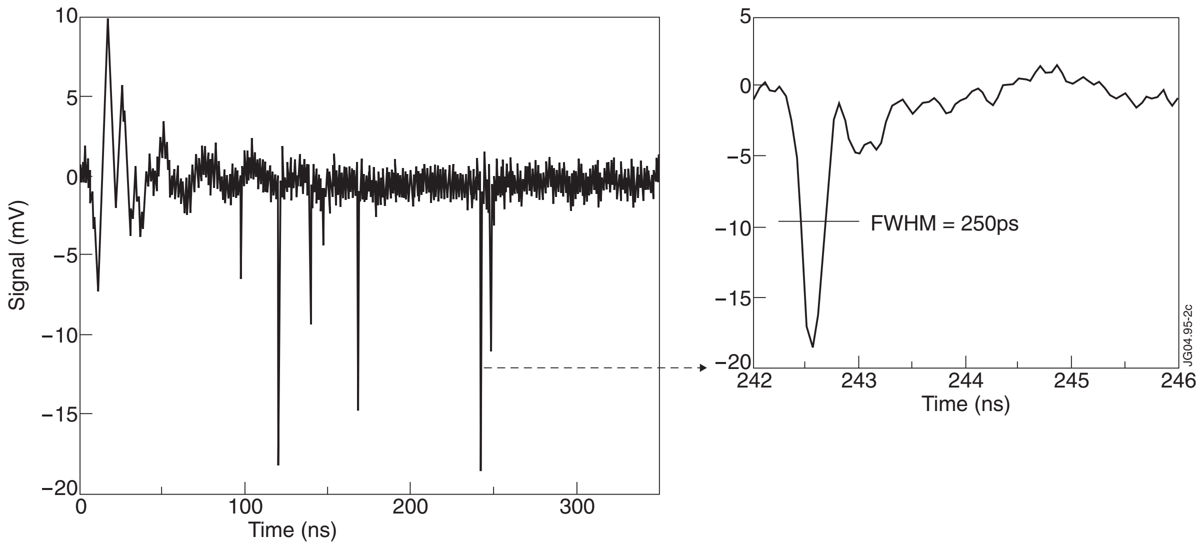

Figure 1: Single Photoelectron events (a) and FWHM (b).

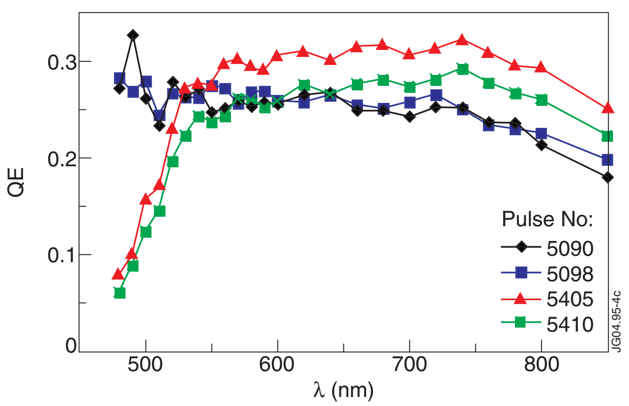

Figure 2: Scaled Quantum Efficiency of the four detectors as a function of input wavelength.

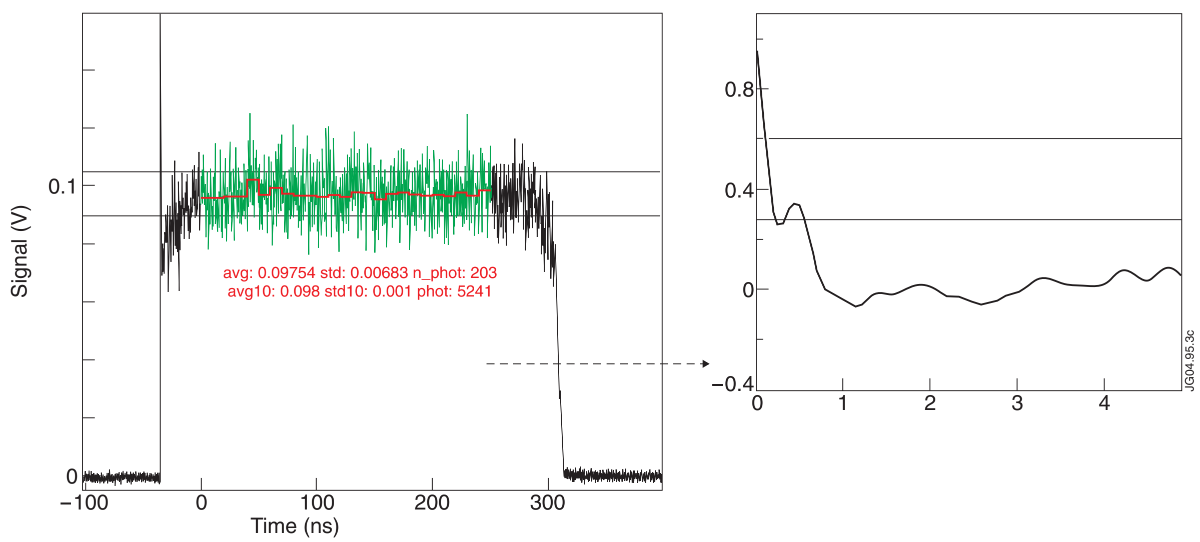

Figure 3: Display of signal to noise measurement and autocorrelation function.

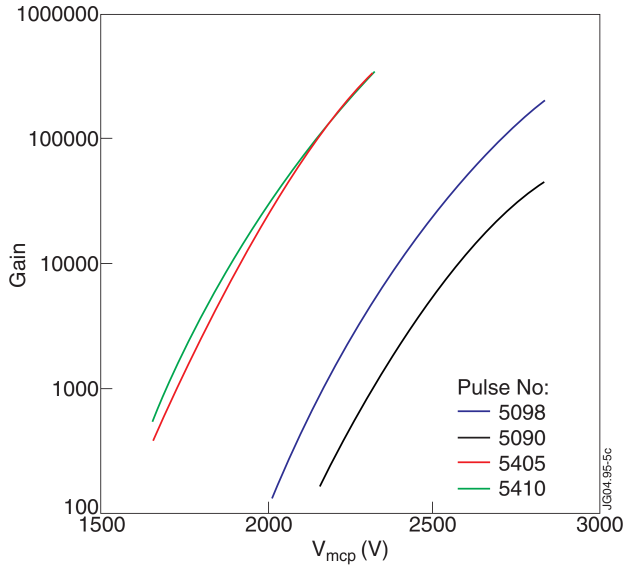

Figure 4: Gain curves of all four detectors.

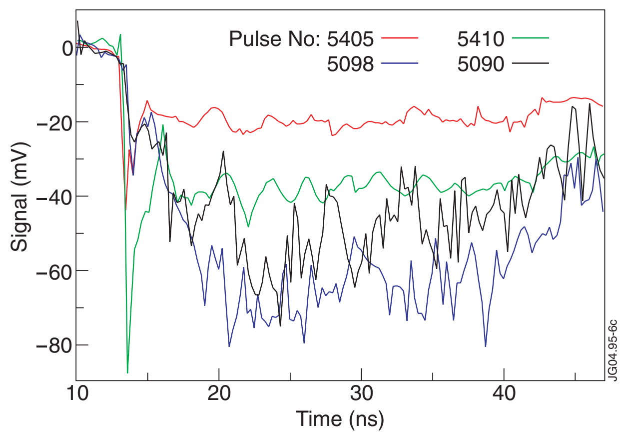

Figure 5: White light source calibration of the four new detectors, showing the difference between the two sets of photomultiplier tubes.

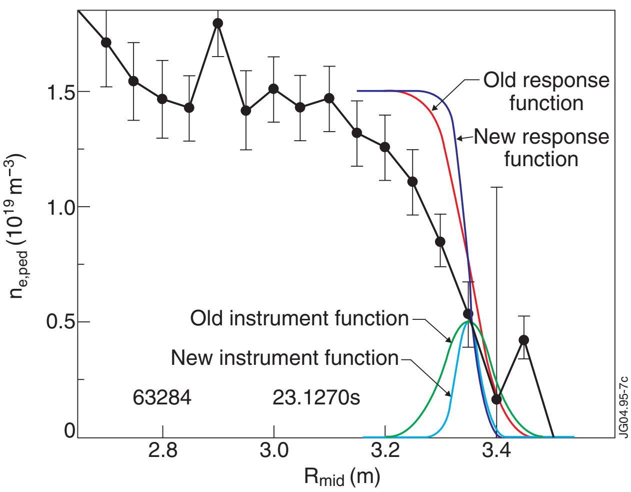

Figure 6: Highest gradients achieved during test operation with high bandwidth oscilloscope.