High-brightness electron beam evolution following laser-based cleaning of a photocathode

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Overview

The Linac Coherent Light Source (LCLS), located at the SLAC National Accelerator Laboratory. Three polycrystalline copper photocathodes have been used in the LCLS injector operation since its initial commissioning.

Laser-based techniques have been used for cleaning metal photocathodes to increase quantum efficiency (QE).

A high intensity laser beam, interacting with the cathode, may ablate the cathode surface and/or remove contamination, thereby resulting in a QE increase.

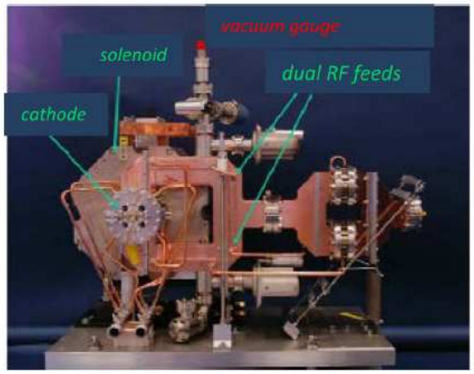
The laser-based cleaning was applied to two separate areas of the current LCLS photocathode on July 4 and July 26, 2011, respectively.

The QE was increased by 8–10 times upon the laser cleaning.

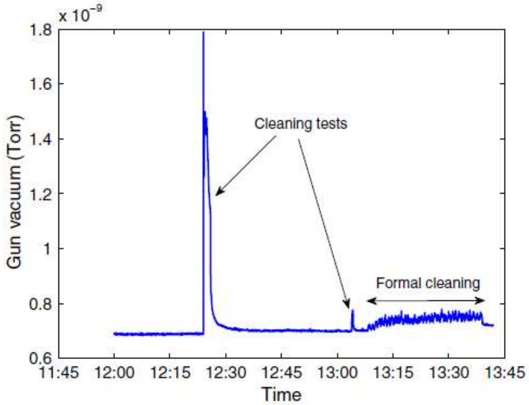
Currently, the QE of the LCLS photocathode is holding constant at about $1.2 \text{x} 10^4$, with a normalized injector emittance of about 0.3 µm for a 150-pC bunch charge.

Laser-based cleaning of a photocathode: Parameters and procedures

The applied laser fluence is a key parameter in the laser based cleaning of metal cathodes.
The laser fluence used for laser cleaning was determined by the ‘‘vacuum activity’’ in the photocathode rf gun.
The applied laser fluence (laser energy for a given laser spot size) had to be gradually increased until a change in vacuum pressure in the rf gun was observed. After the first run of the cleaning, the QE increased to ~1x10^5 from an original value of 6x10^6.



Picture of the LCLS rf gun and its accessories



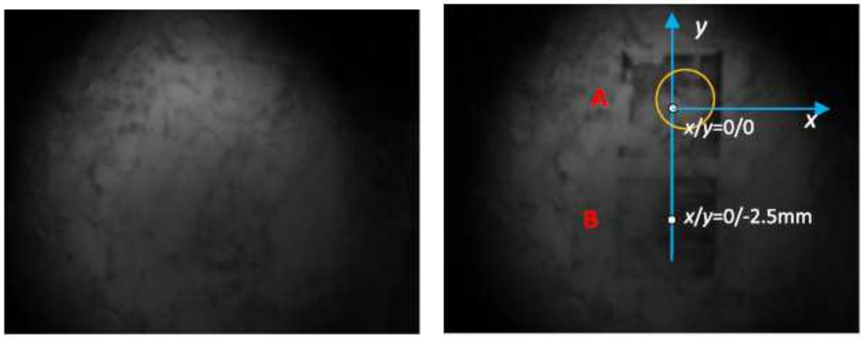
Typical ‘‘vacuum activity’’ in the rf gun waveguide during the laser-cleaning process: about 0.5x10^{10} Torr of the pressure rise in the gun waveguide (blue) is observed during the laser-cleaning process.

Major parameters for the cleaning of the third LCLS cathode

Laser pulse energy (μJ)	17–20
Laser rms spot size on cathode, σ_x/σ_y (μm rms)	30/30
Laser scan step size (μm)	30
Laser shots on each spot	60 or 120
Laser beam rate (Hz)	120
Base vacuum on the gun waveguide prior to the laser cleaning with rf off (Torr)	$\sim 7 \times 10^{-10}$
Vacuum rise on the gun waveguide during the cleaning with rf off (Torr)	$\sim 0.5 \times 10^{-10}$
Gun rf power during the cleaning	rf power off
QE measurements:	
QE before the cleaning	$\sim 5 \times 10^{-6}$
QE after three runs of cleaning	$\sim 4 \times 10^{-5}$
QE measured at:	
Laser launch phase	30° from zero crossing
Peak gun accelerating field (MV/m)	115
Laser spot size on the cathode	1 mm diameter

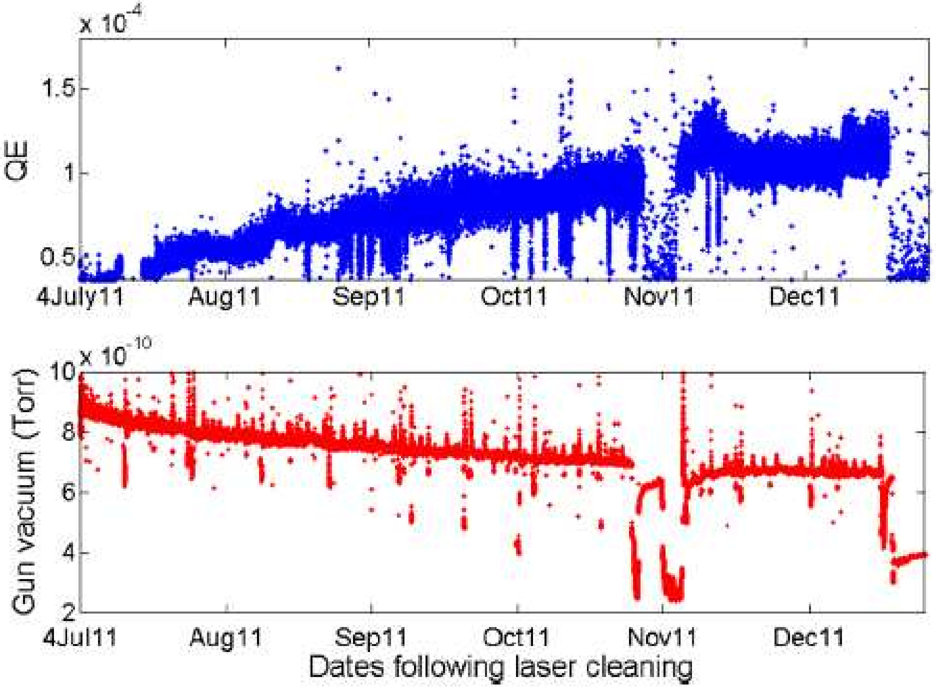
Evolution of QE and emittance following cathode laser cleaning

Two separate square areas on the LCLS cathode (2 mm2 mm each) were processed by the laser-based cleaning.

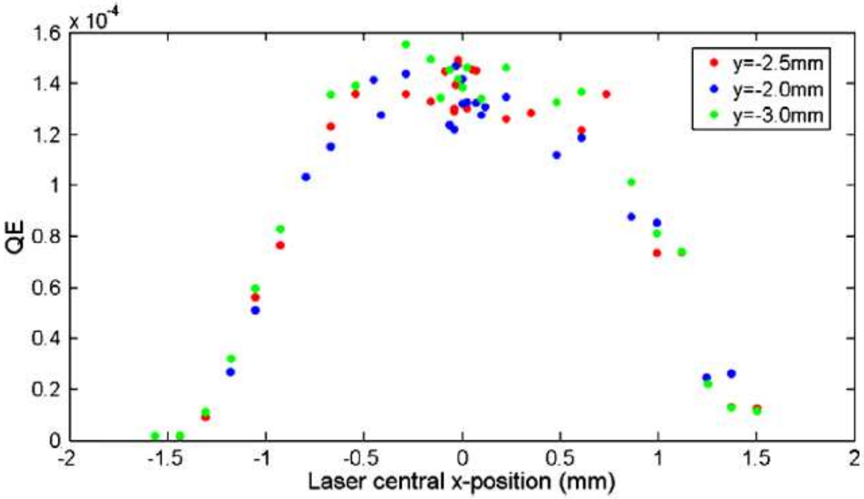


(a) (b)

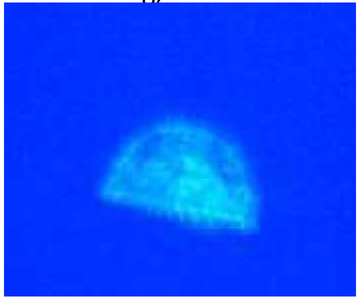
White light images of the LCLS cathode before (a) and after (b) the laser cleaning



Evolution of the QE (top) and gun-waveguide vacuum (bottom) during the five months following the laser cleaning, for the cathode spot with yellow circle.



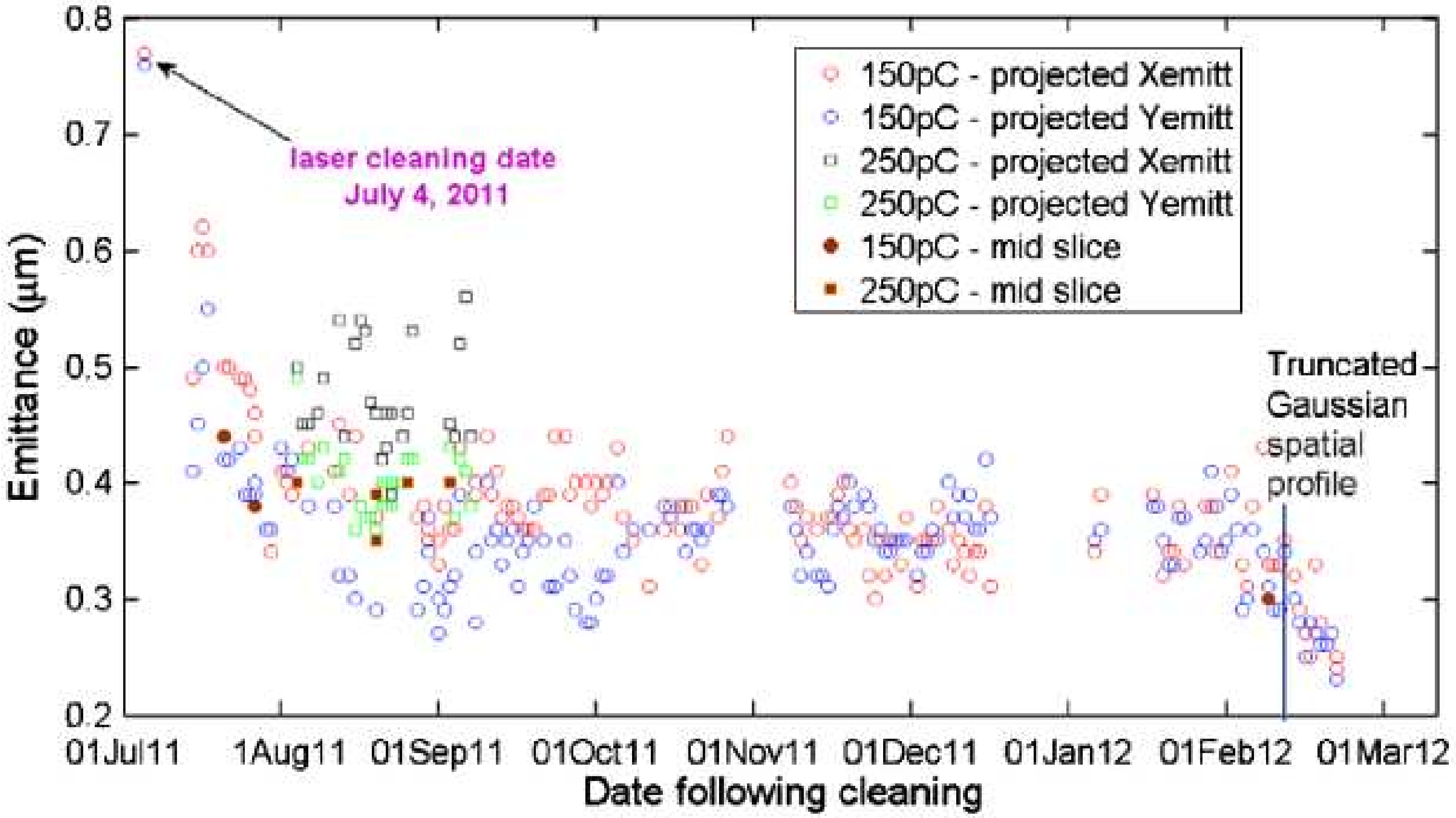
The QE measured eight months following laser cleaning, for area B, using a 1-mm-diameter laser spot size. The area has a 2.5 mm y offset from the cathode center. Within 0.5 mm of the central x location, the full laser spot was located within the cleaned area, while it was located completely outside the cleaned area for a central x location beyond +1.5 mm or -1:5 mm. For central x locations at ±1.0 mm, one half of the laser spot was in a cleaned area while the other half was in an uncleaned area.



The QE image for a laser spot half on a cleaned area and half on an uncleaned area. The image was taken at a screen located about 1.43 m downstream of the gun, with a 20 pC bunch charge.

Emittance evolution

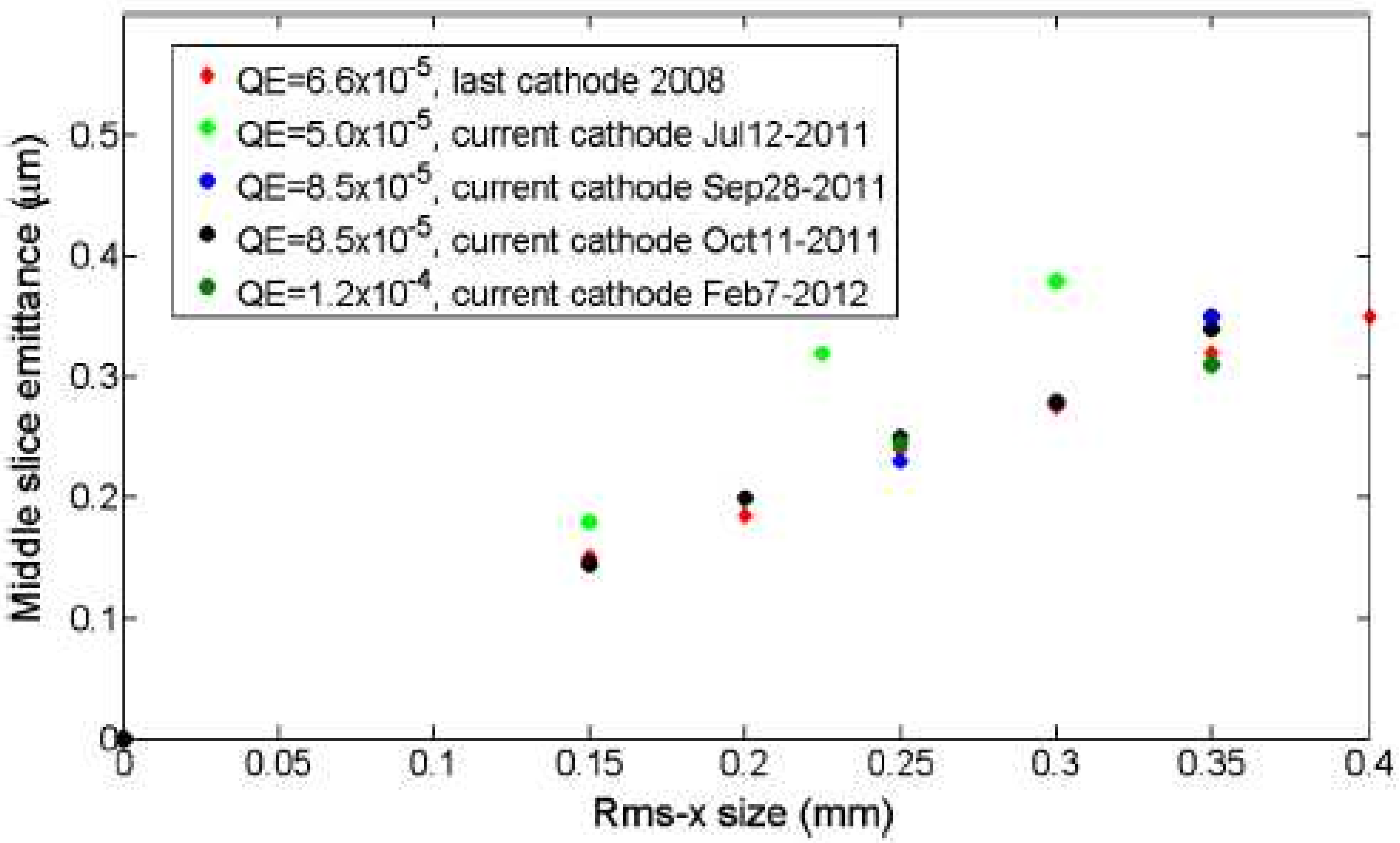
The LCLS injector emittance measurements are made using a quadrupole scan. After acceleration of the electron beam to 135 MeV, the beam is intercepted by a 1-µm thick aluminum screen.



Emittance evolution for the cathode spot with yellow circle: the emittance assumes a normal value, between 0.3 and 0.4 µm (for 150 pC), within 2–3 weeks following the laser cleaning. The cathode spot being used for user operations is close to the cathode center. No data is shown from the middle of December 2011 to early in January 2012 since the LCLS machine was shut down. The emittance improvement after February 9, 2012 is due to use of a Gaussian-cut laser spatial profile, rather than a pseudouniform profile.

Thermal emittance versus QE

The thermal emittance is taken from the core time-sliced emittance measurements at 20 pC as a function of laser spot size, assuming that space charge forces and other emittance-growth sources are negligible for this charge.

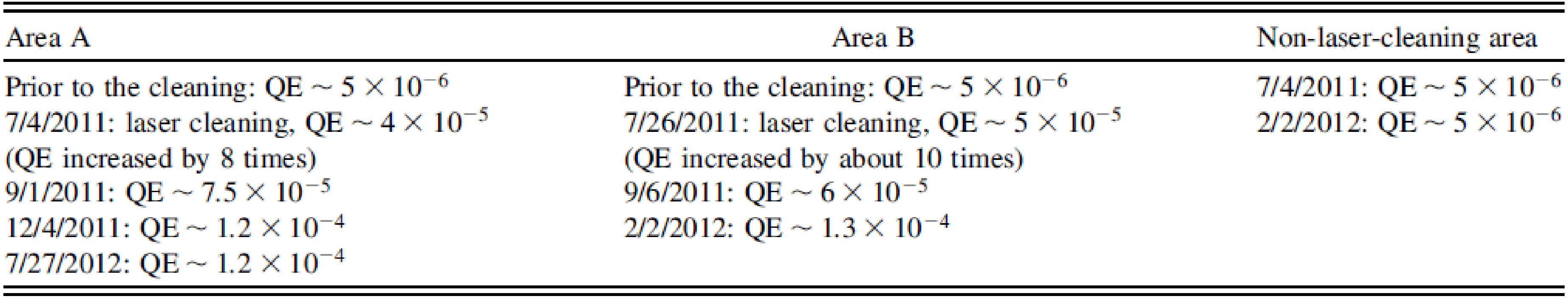


Thermal emittance for the previous 2nd LCLS cathode (red squares), which was never laser-cleaning processed, and the current third LCLS cathode, which was processed by the laser cleaning. Laser cleaning of the current cathode was performed on July 4, 2011.

Conclusion

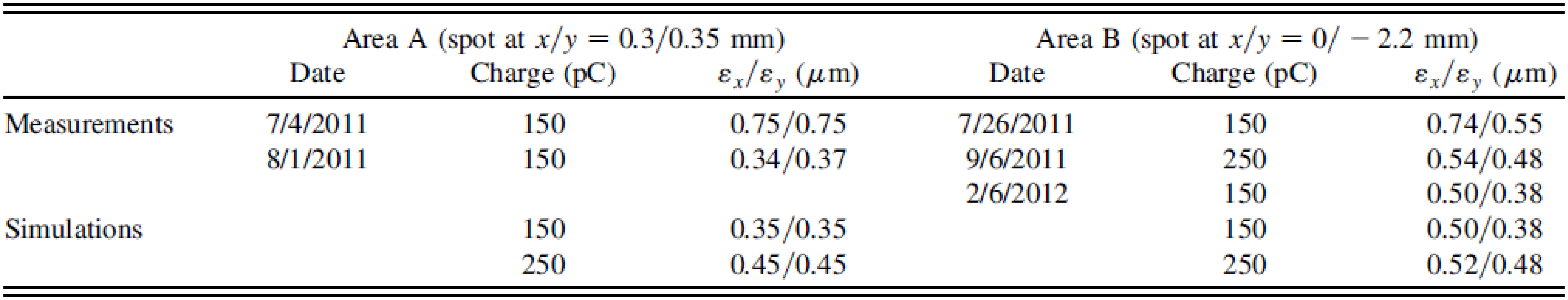
- The QE was enhanced by 8–10 times upon the laser cleanings.
- Currently, the LCLS photocathode QE is holding constant at about 1.2x10^{4}, with a normalized injector emittance of about 0.3 µm for a 150-pC bunch charge.
- Similar evolutions of both QE and emittance for the two separate areas exposed to the laser cleaning are observed.
- With the proper procedures, the laser-cleaning technique appears to be a viable tool to revive the LCLS photocathodes for x-ray FEL operations.
- Measurements show that the LCLS cathode with different QE (up to a factor of 2) has similar thermal emittances, which suggests that cathode surface contamination impacting QE may not modify the work function, and thereby the thermal emittance.

Summary of the QE evolution for the third LCLS cathode.



Area A	Area B	Non-laser-cleaning area
Prior to the cleaning: QE ~ 5×10^{-6}	Prior to the cleaning: QE ~ 5×10^{-6}	7/4/2011: QE ~ 5×10^{-6}
7/4/2011: laser cleaning, QE ~ 4×10^{-5}	7/26/2011: laser cleaning, QE ~ 5×10^{-5}	2/2/2012: QE ~ 5×10^{-6}
(QE increased by 8 times)	(QE increased by about 10 times)	
9/1/2011: QE ~ 7.5×10^{-5}	9/6/2011: QE ~ 6×10^{-5}	
12/4/2011: QE ~ 1.2×10^{-4}	2/2/2012: QE ~ 1.3×10^{-4}	
7/27/2012: QE ~ 1.2×10^{-4}		

Summary of the emittance evolution following the laser cleanings.



	Area A (spot at $x/y = 0.3/0.35$ mm)			Area B (spot at $x/y = 0/-2.2$ mm)		
	Date	Charge (pC)	$\varepsilon_x/\varepsilon_y$ (μm)	Date	Charge (pC)	$\varepsilon_x/\varepsilon_y$ (μm)
Measurements	7/4/2011	150	0.75/0.75	7/26/2011	150	0.74/0.55
	8/1/2011	150	0.34/0.37	9/6/2011	250	0.54/0.48
				2/6/2012	150	0.50/0.38
Simulations		150	0.35/0.35		150	0.50/0.38
		250	0.45/0.45		250	0.52/0.48