Fluorescence and Raman studies of micro-machined glasses exposed to femtosecond pulses at variable repetition rate

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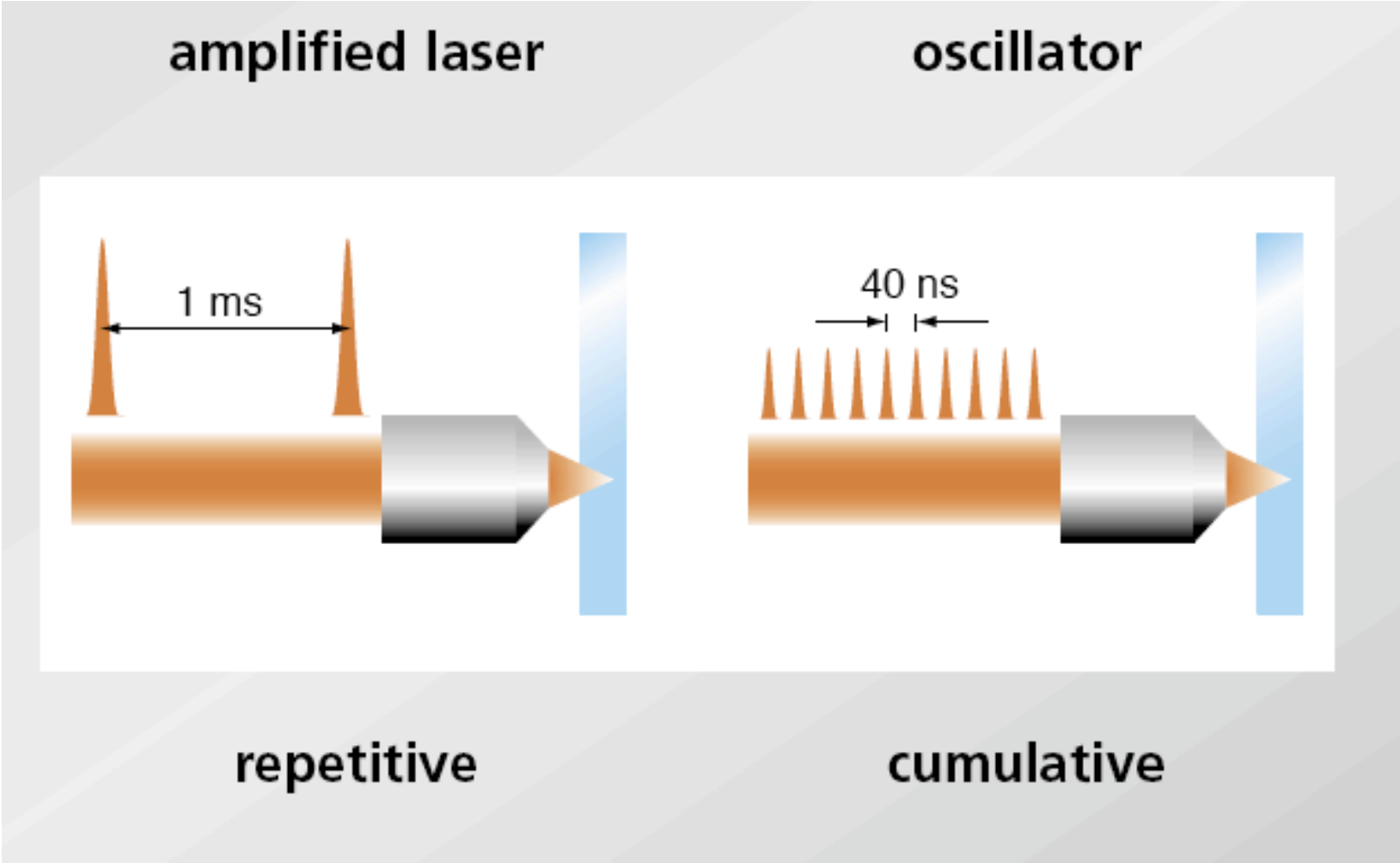
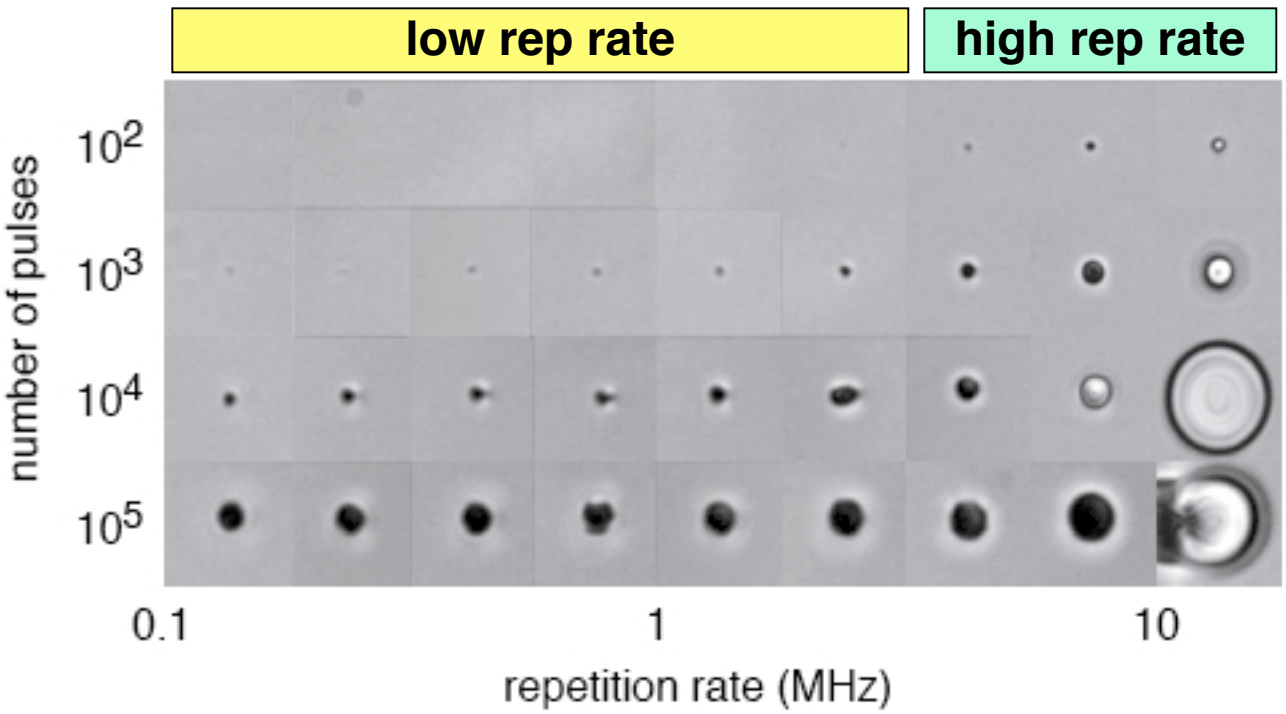
Fs laser micromachining

Difference in low and high rep rate behavior



Difference in low and high rep rate behavior



Is the structure of the modified material different for the low and high rep rate regimes ?

Use confocal **fluorescence** and **Raman** microscopy

defects **network structure**

Previous work in fused silica- 1KHz rep rate

Fluorescence: **modified regions contian NBOHC defects**

annealing of defects under 488 nm cw light

Raman: **modified regions have higher concentrations of**

3- and 4-membered rings $\longrightarrow$

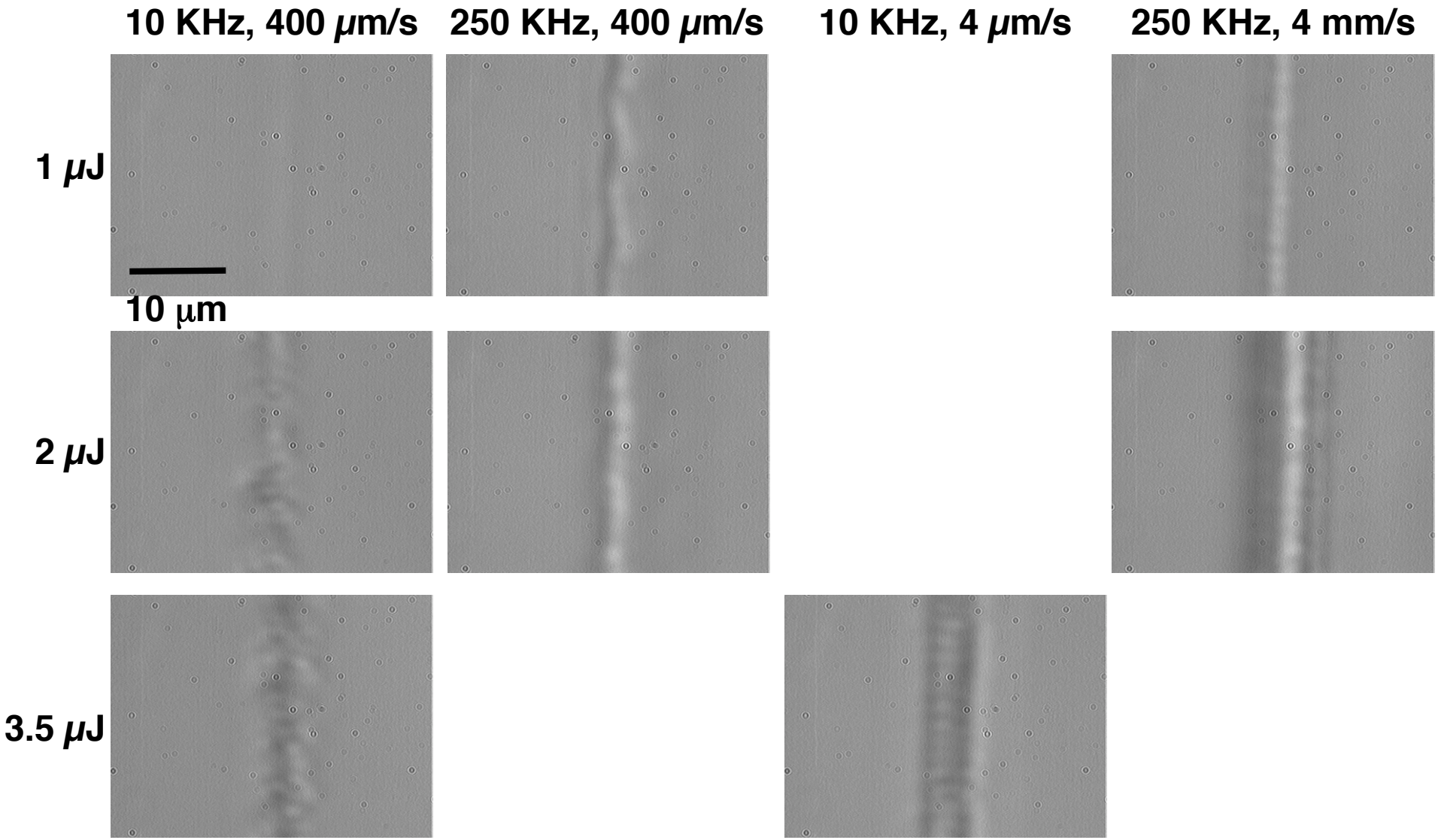
increase in density and refractive index

Chan et al Optics Letters, **26**, 1726 (2001).
Chan et al. Applied Physics A**76**, 367 (2003).

glasses and writing conditions

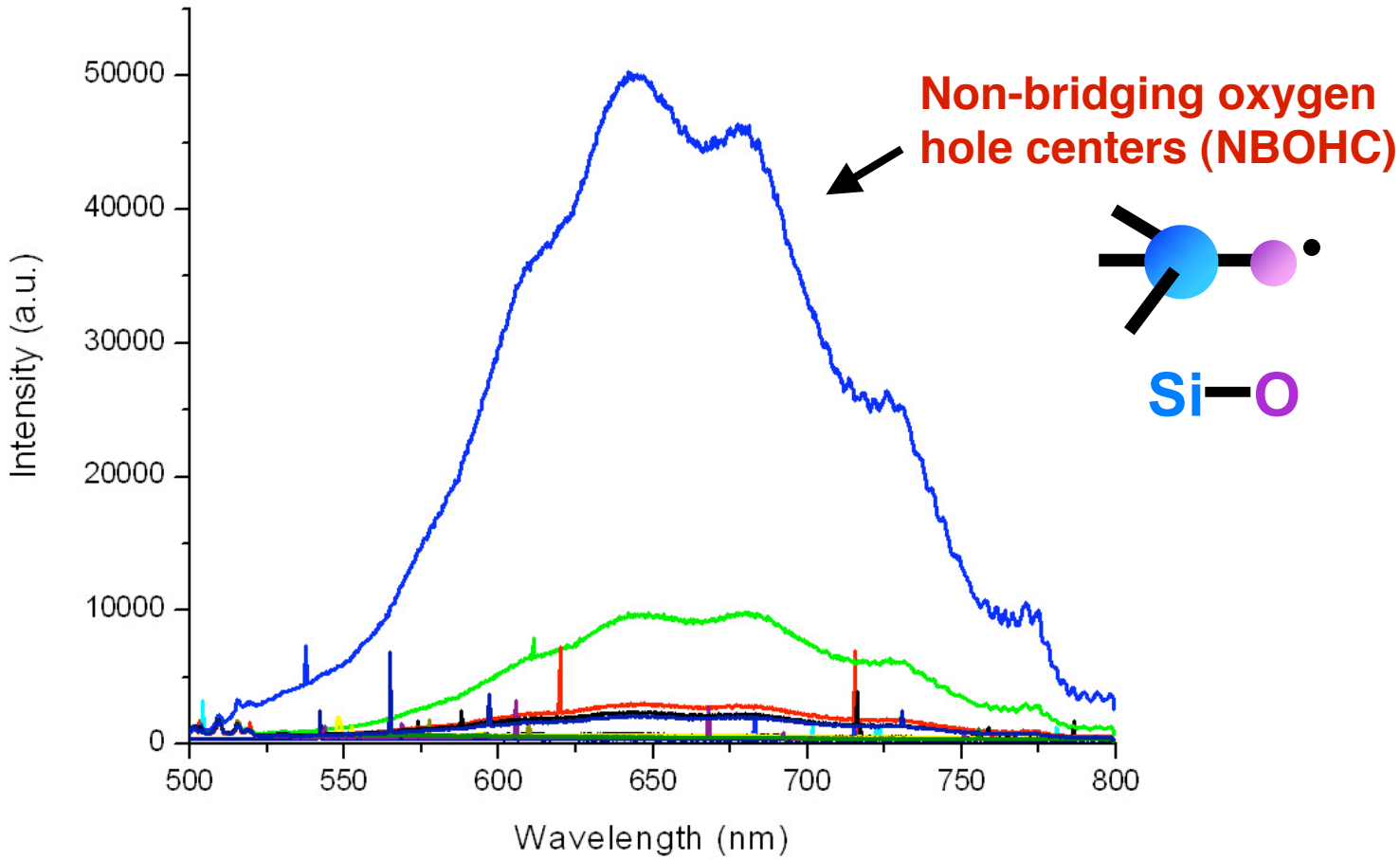
	amplified Ti-Sa laser 0.4 NA objective		Ti-Sa oscillator 1.4 NA objective
sample	fused silica	borosilicate (Corning 2947)	
pulse energy	1-3.5 μJ	1-3.5 μJ	6 nJ
rep rate	10-250 KHz	10-250 KHz	25 MHz
scan speed	4-400 μm/s	4-400 μm/s	40-40,000 μm/s

Fused silica - low rep rate



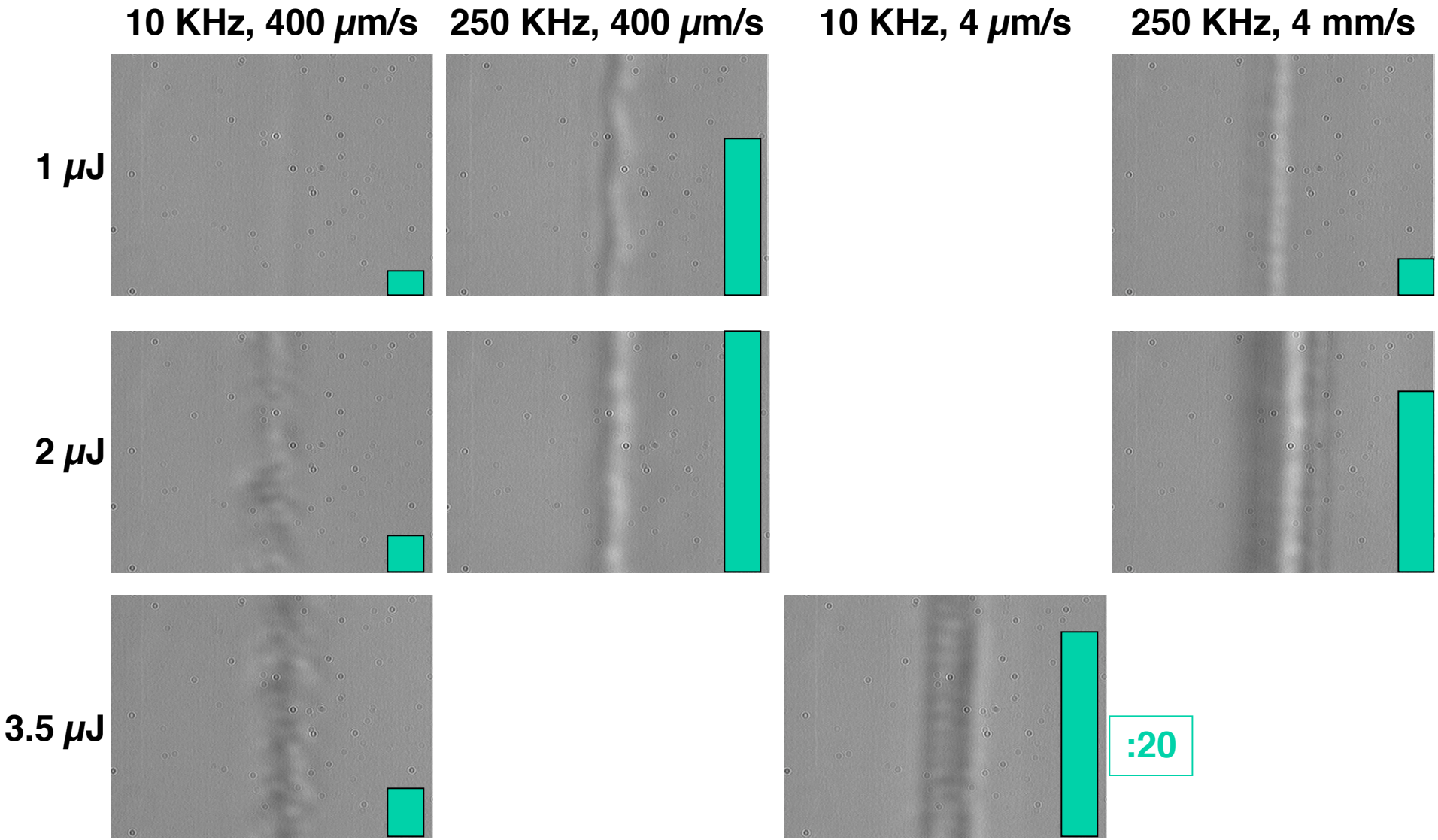
Fluorescence of modified lines in fused silica

excitation with 488 nm light

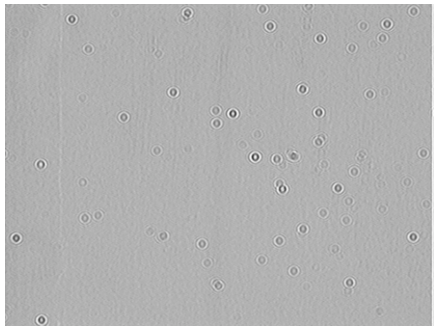
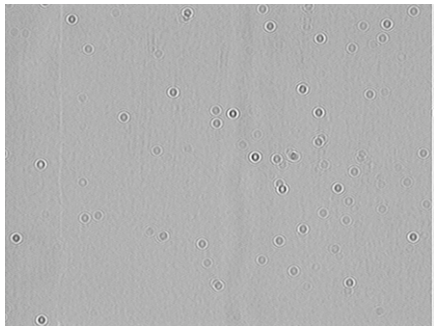
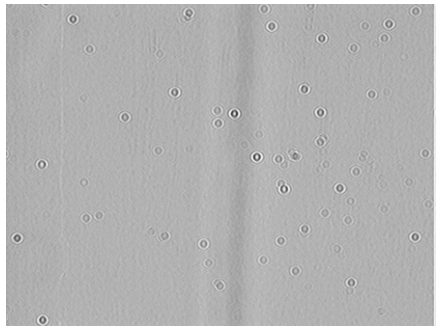
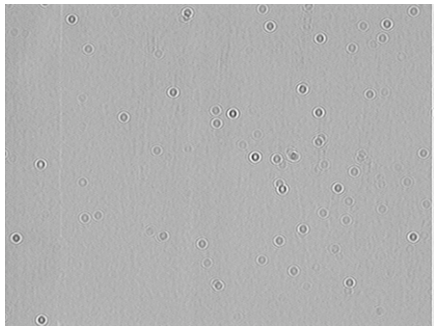
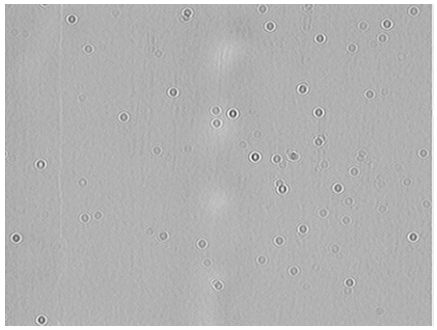
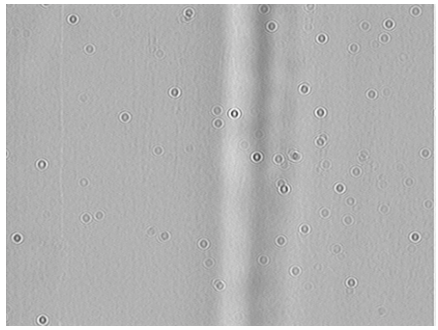
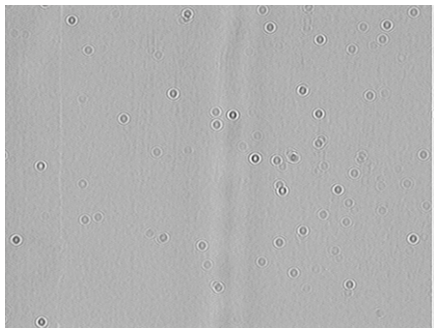
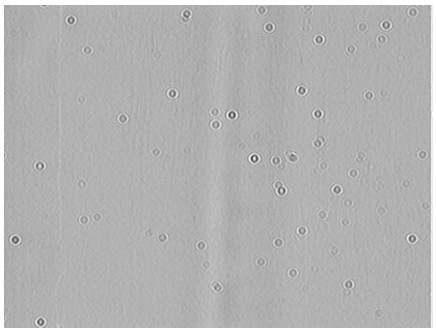


Chan *et. al*, Appl. Phys. A76, 367 (2003)
Sun *et. al*, J. Phys. Chem. B, 104, 3450 (2000)

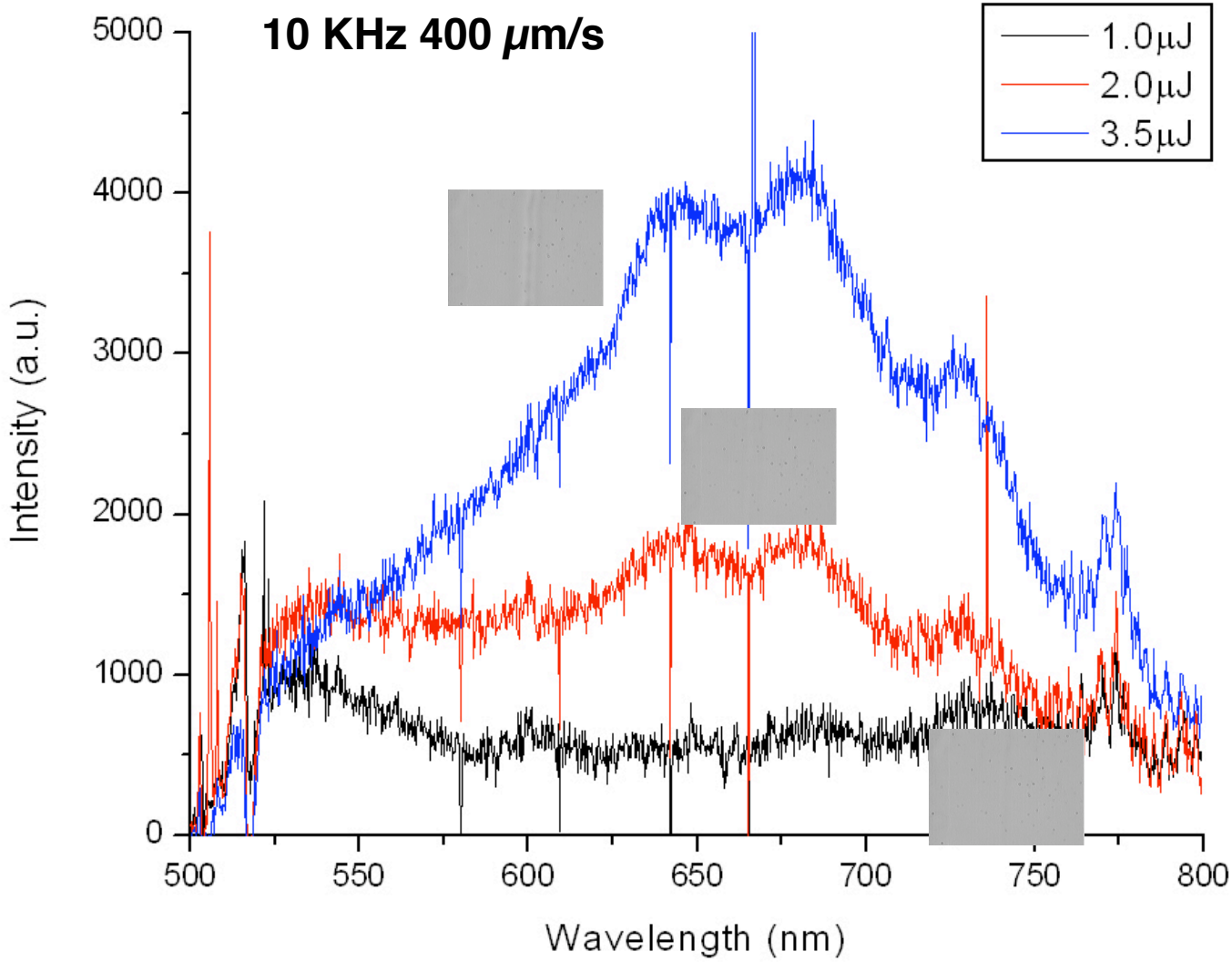
Total fluorescence intensity in fused silica



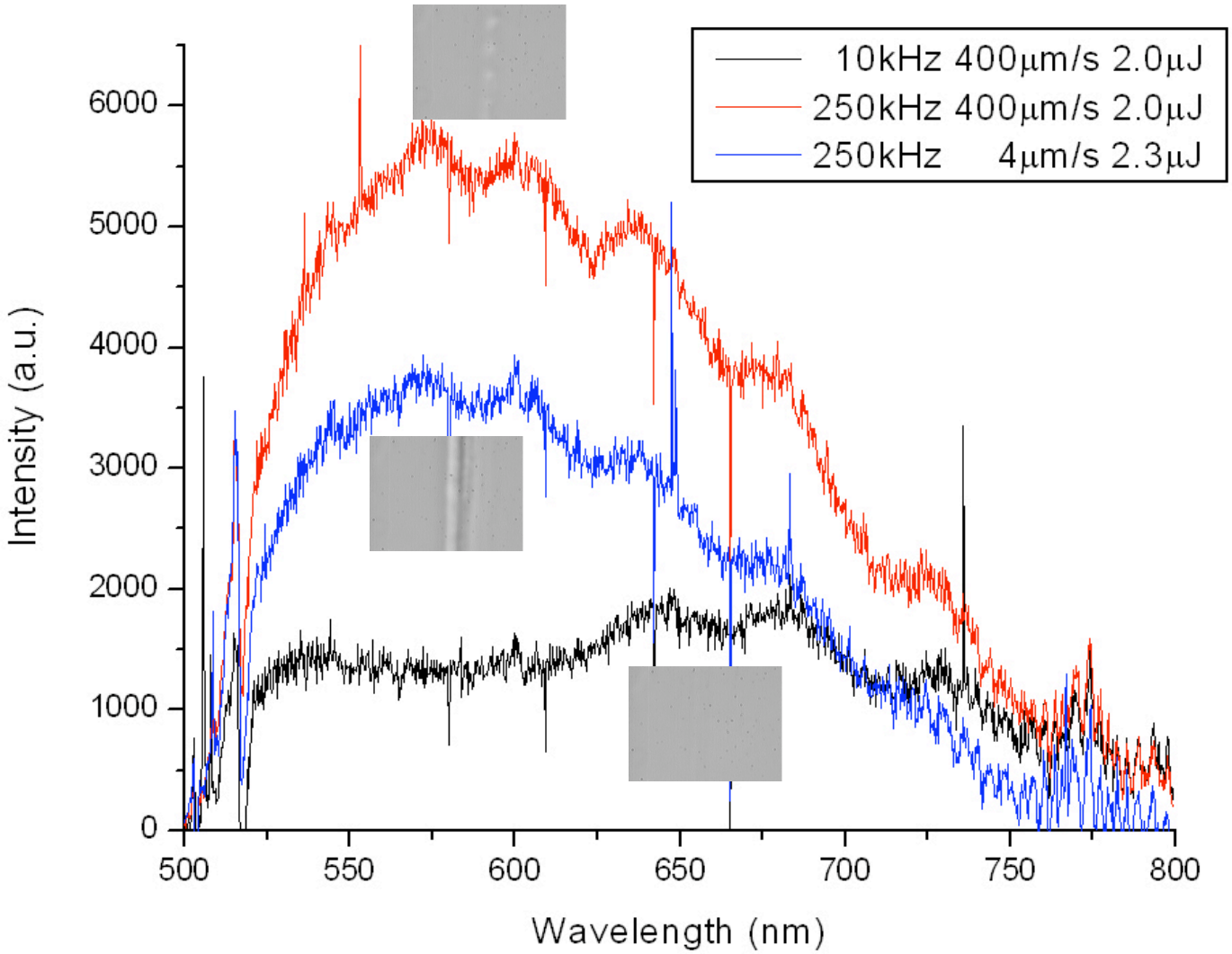
Borosilicate glass - low rep rate

	10 KHz, 400 μm/s	250 KHz, 400 μm/s	10 KHz, 4 μm/s	250 KHz, 4 mm/s
1 μJ				
2 μJ				
3.5 μJ				

Fluorescence in borosilicate glass

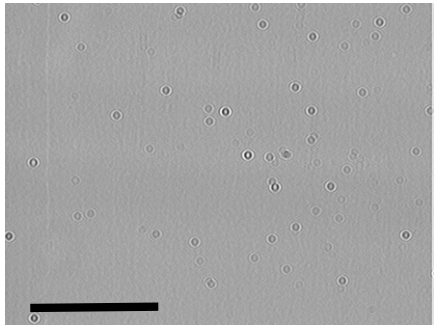


Fluorescence in borosilicate glass



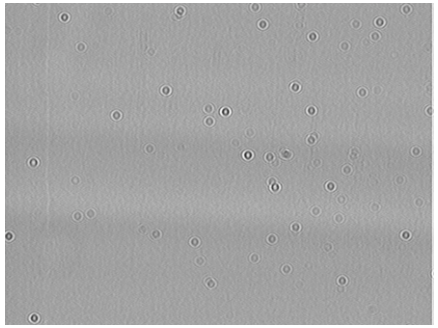
borosilicate glass- high rep rate

40,000 μm/s

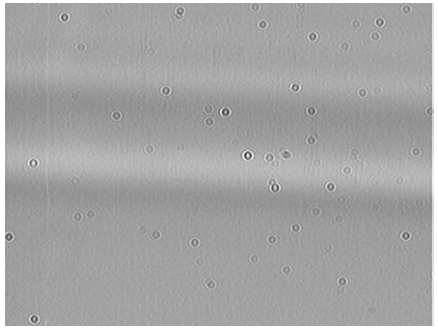


10 μm

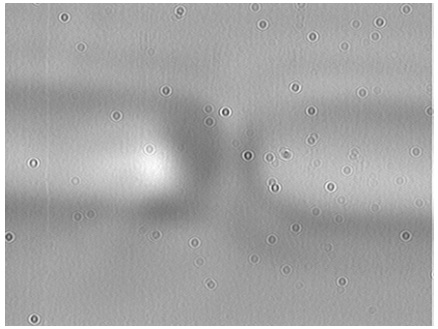
4000 μm/s



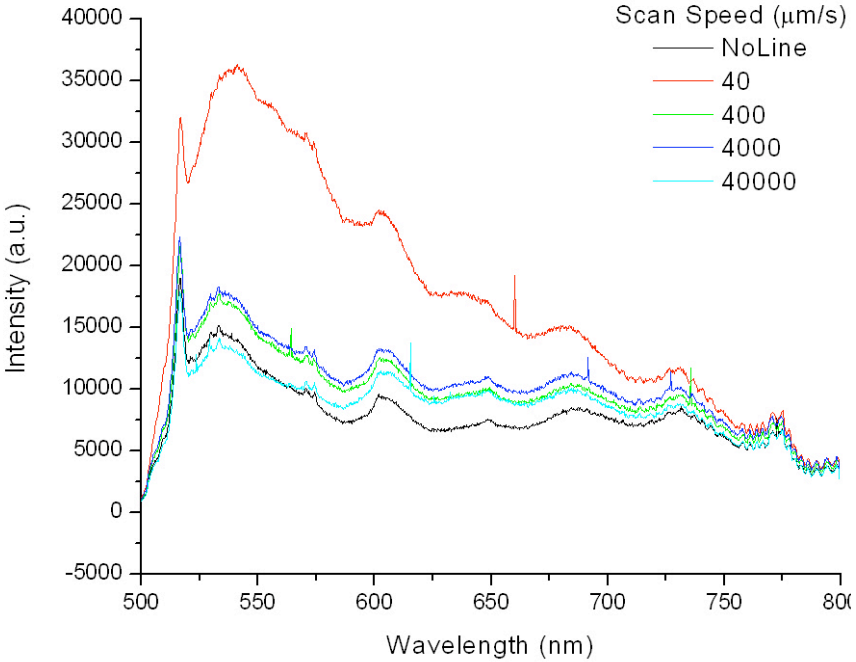
400 μm/s

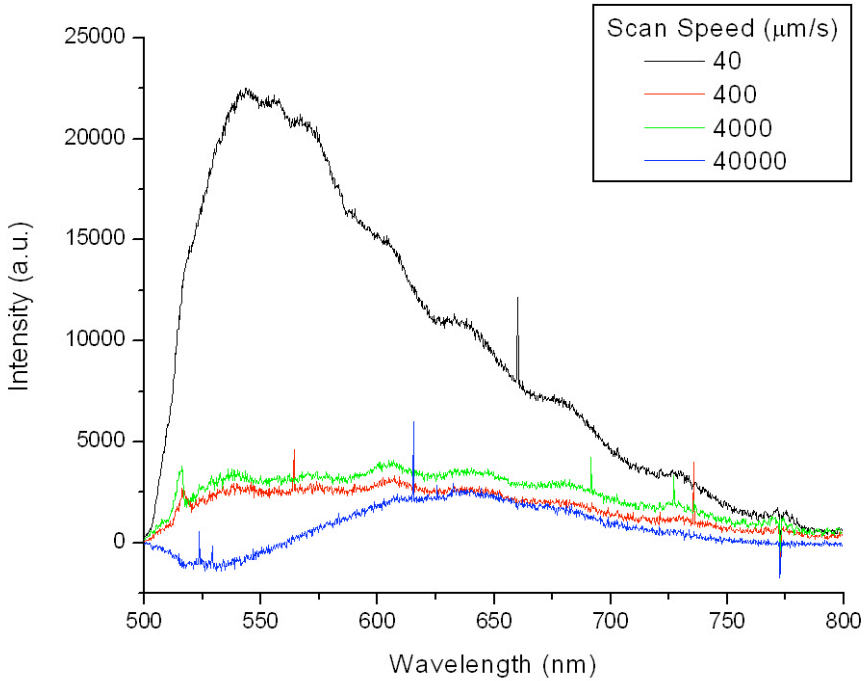


40 μm/s



Fluorescence in borosilicate glass-high rep rate





Summary

- Fluorescence experiments show that NBOHC are formed as a results of fs laser exposure in fused silica and borosilicate glass
- Defects are formed at both low and high laser rep rate
- The defect concentration increases with increase of fs dose possible annealing of defects at very high dose

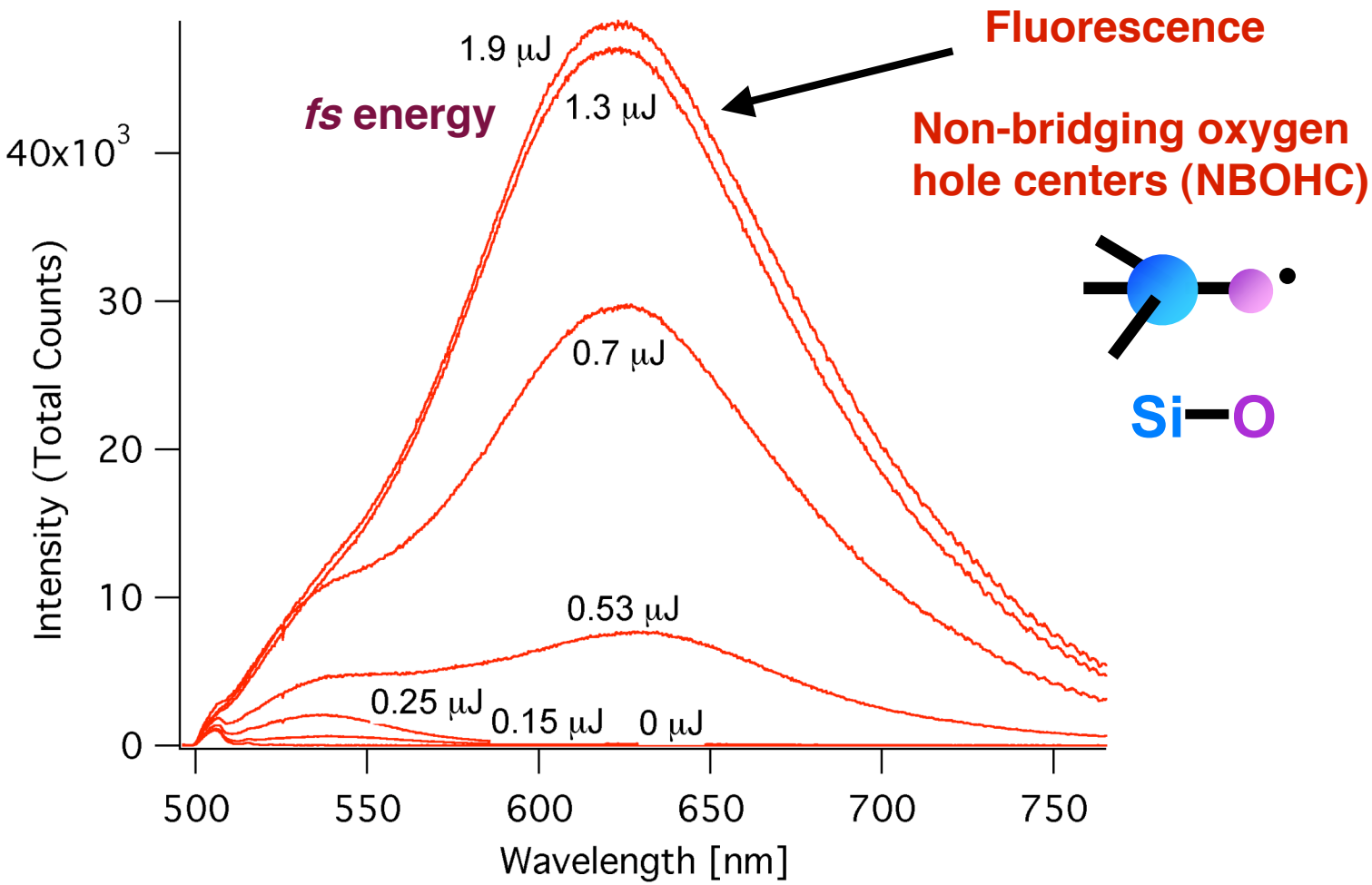
Still to do:

Characterization of overall network structure of modified lines using Raman spectroscopy

Probe for spatial variations of fluorescence across lines in high rep rate (cumulative) regime

Fluorescence of fs-modified fused silica

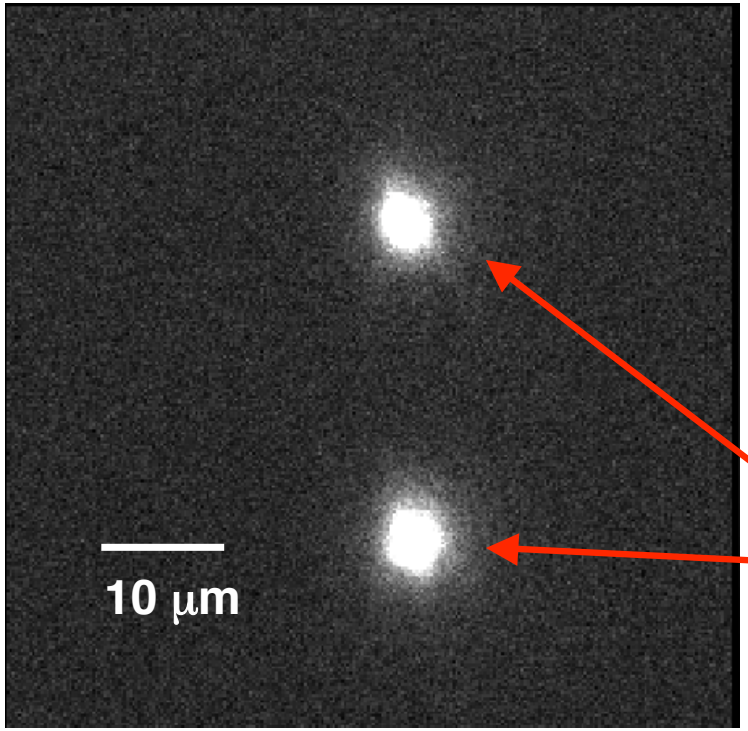
excitation with 15 mW 488 nm light

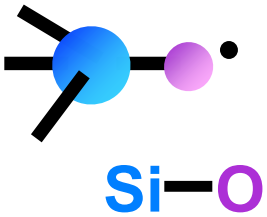


Chan *et. al*, Appl. Phys. A 76, 367 (2003)
Sun *et. al*, J. Phys. Chem. B, 104, 3450 (2000)

Fluorescence images of waveguides show spatial profile of color centers

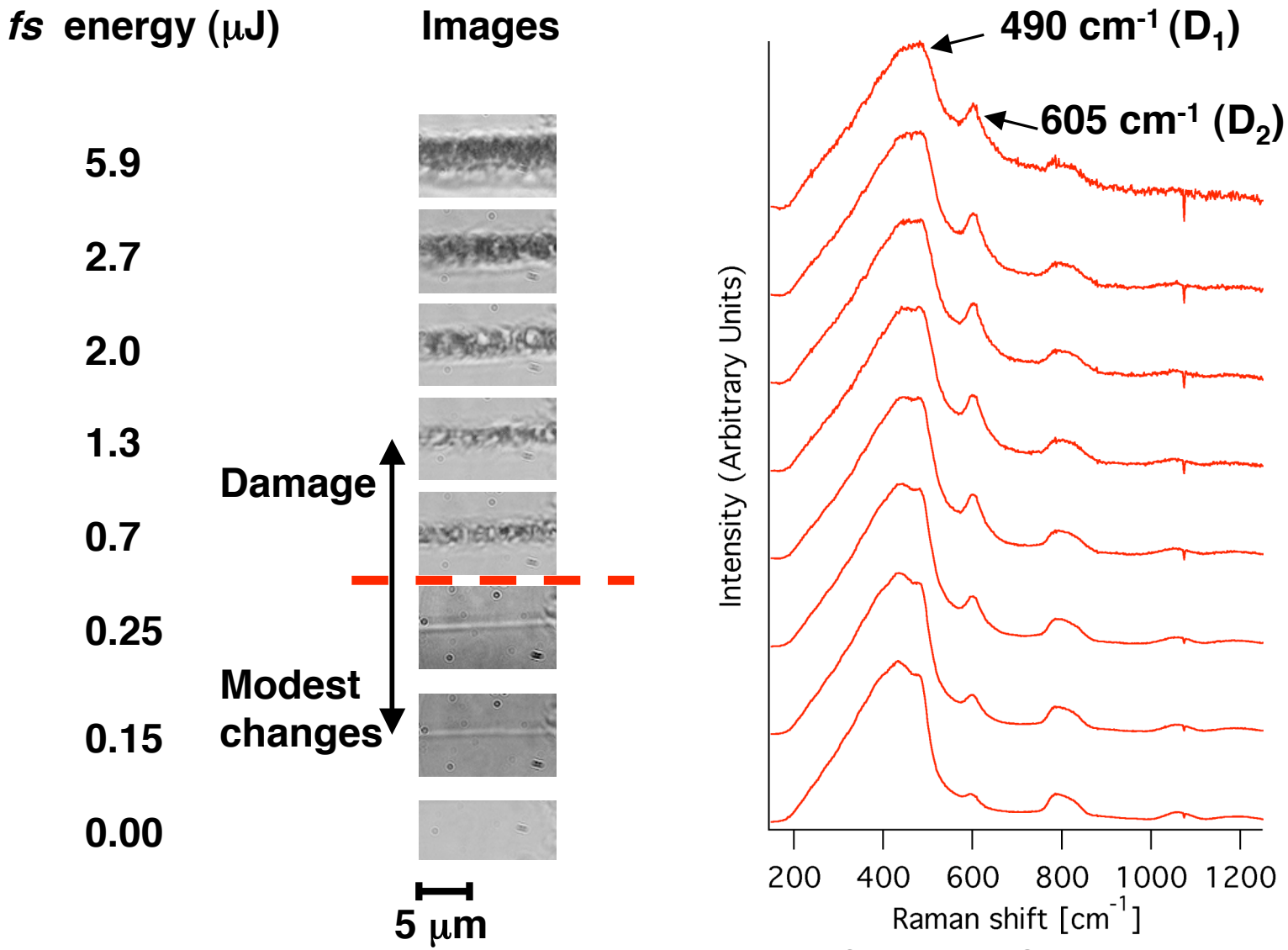
scan sample with focused 488 nm beam (100x objective) yields x-y spatial profile of color centers





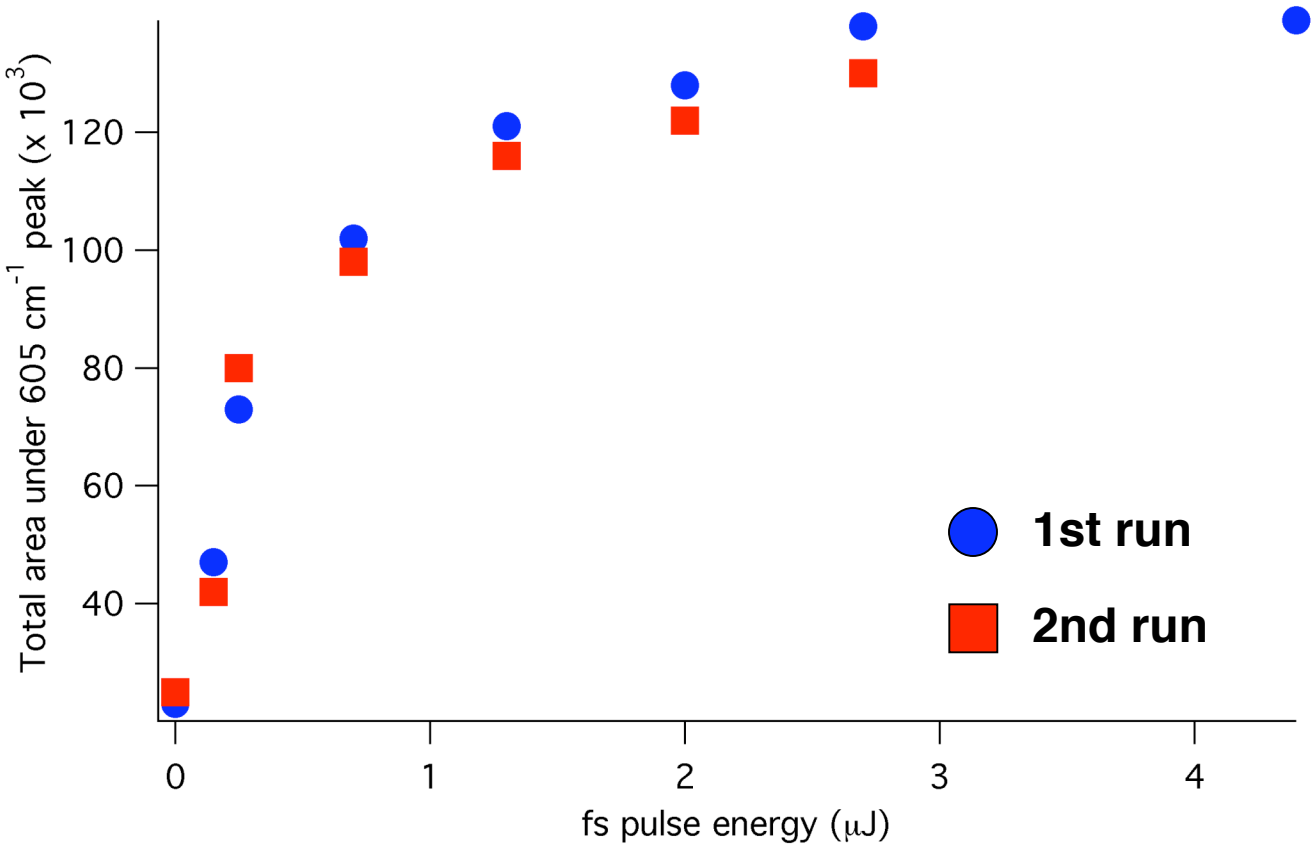
non-bridging oxygen hole centers (NBOHC) located within waveguide regions

The 490 cm^{-1} and 605 cm^{-1} peaks in the Raman spectra increase with fs pulse energy



Chan *et. al*, Opt. Lett., 26, 1726 (2001)

Increase of the D_2 peak area with fs pulse energy



Increase in peak area saturates to a maximum of ~5 times the original area