

Early stages of femtosecond laser-induced formation of silicon microspikes

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Mengyan Shen

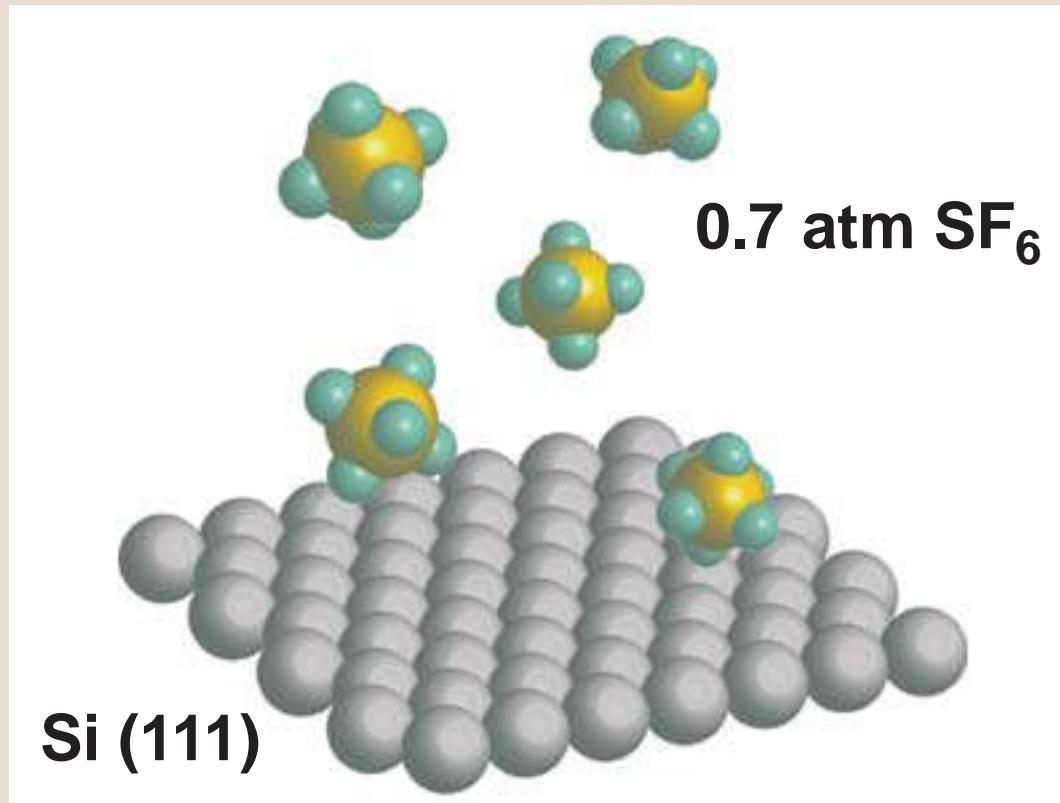
James E. Carey

Eric Mazur

Harvard University

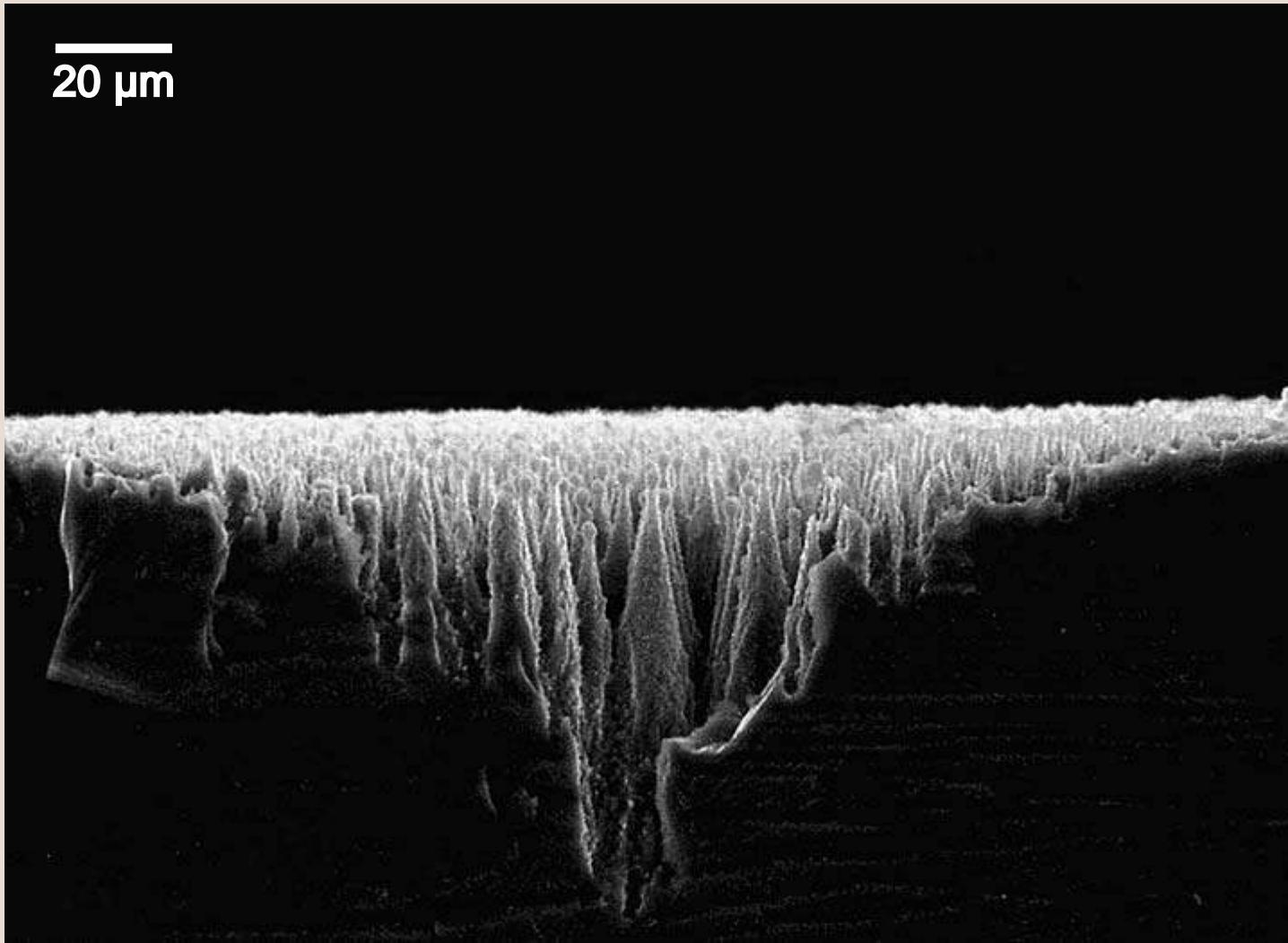
**MRS Fall Meeting
2 December 2002**

Silicon microspikes

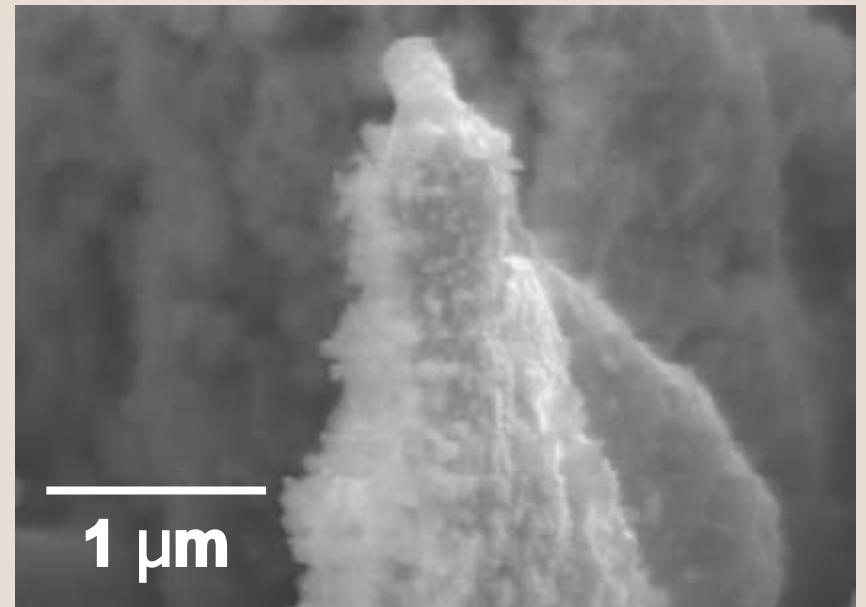
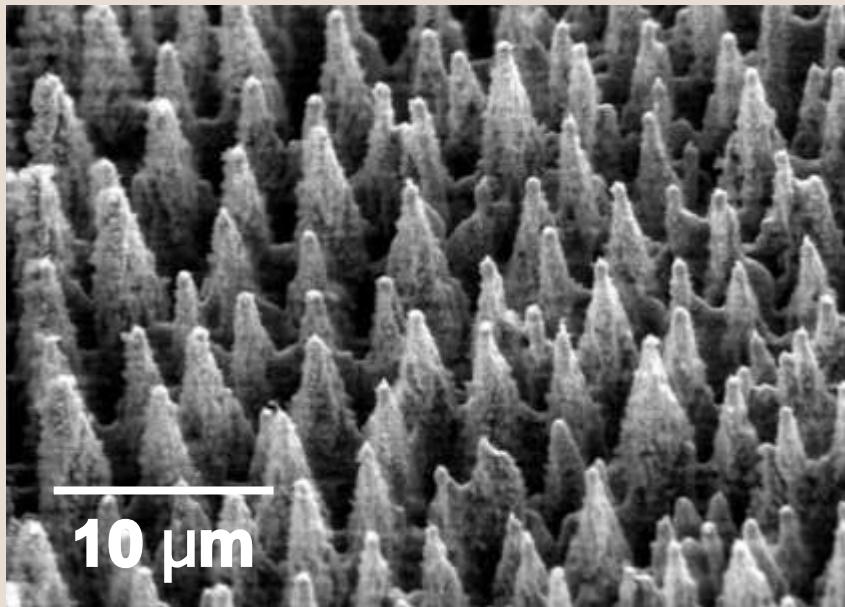


**Irradiate surface with ultrashort laser pulses
(780 nm, 100 fs, 10 kJ/m²)**

Silicon microspikes



Silicon microspikes

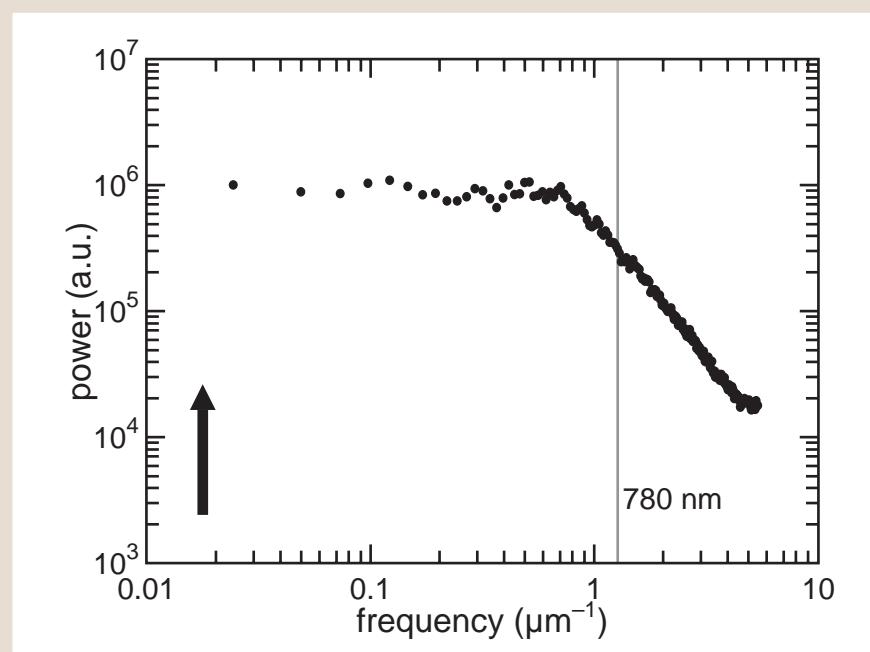
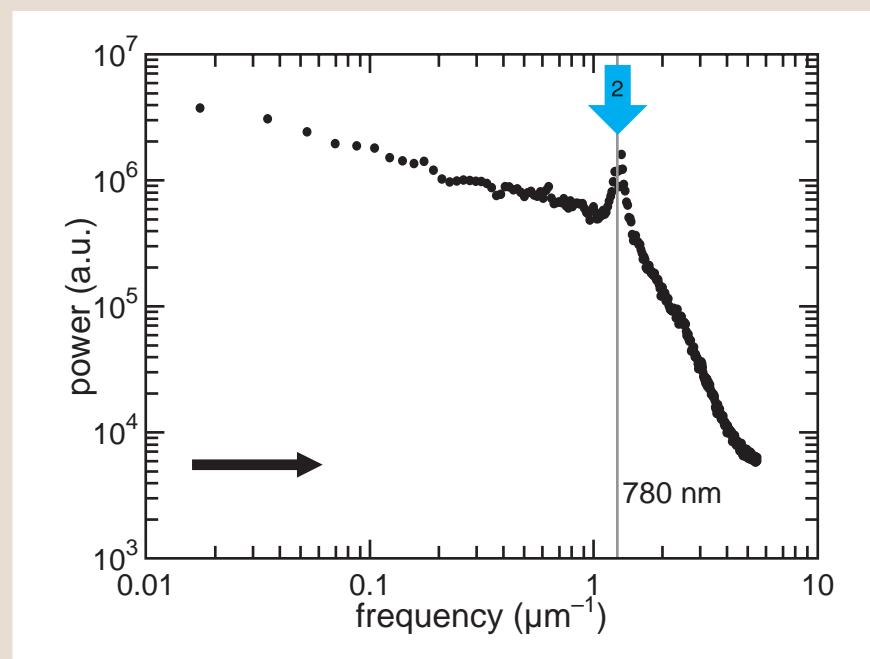
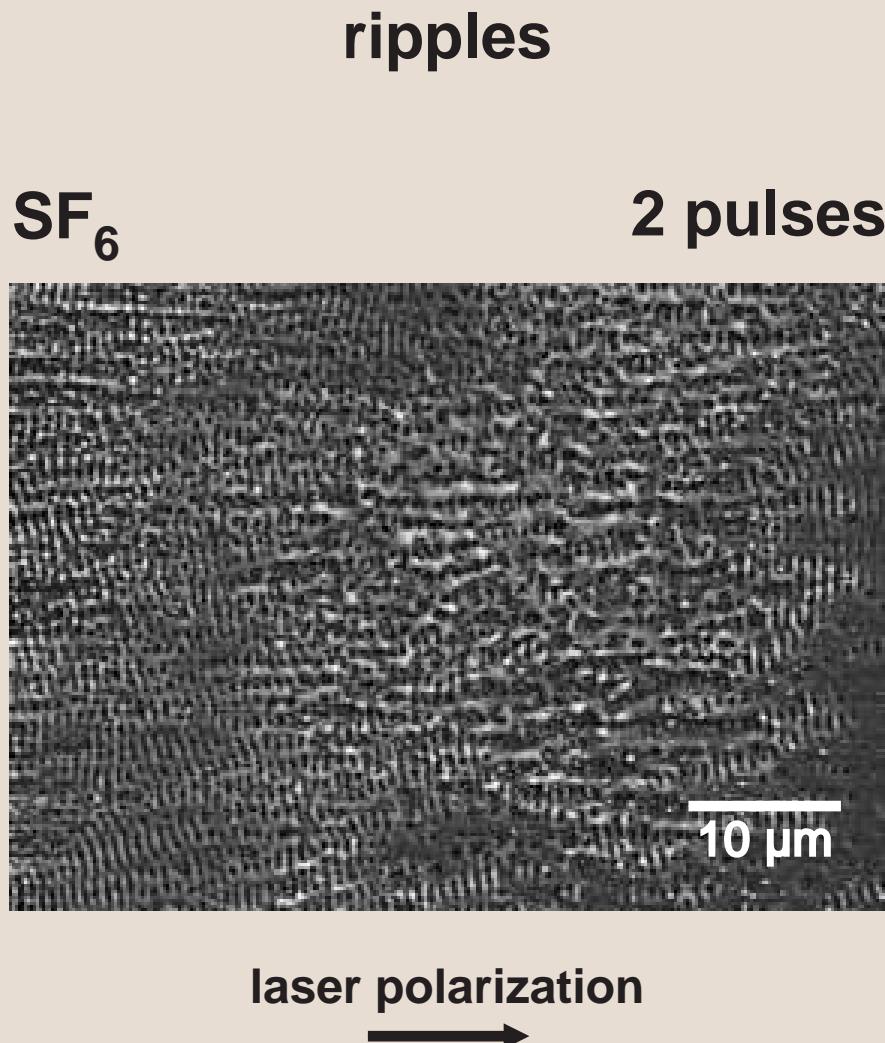


How do microspikes form?

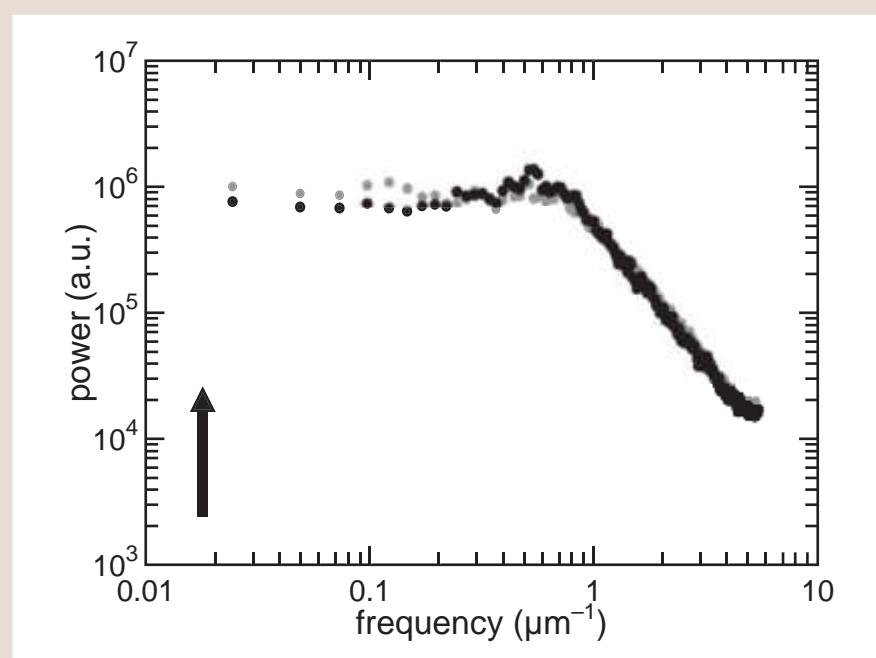
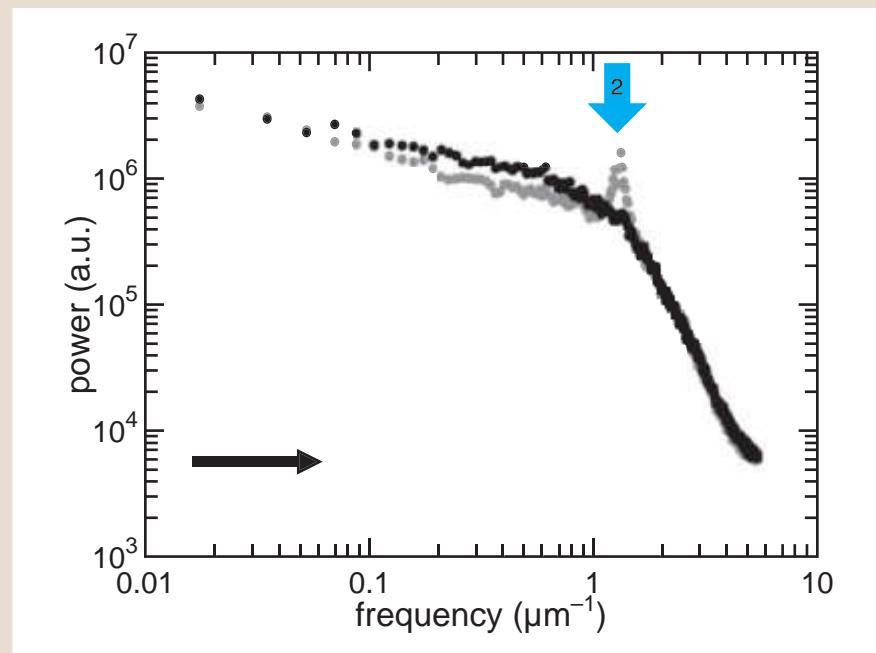
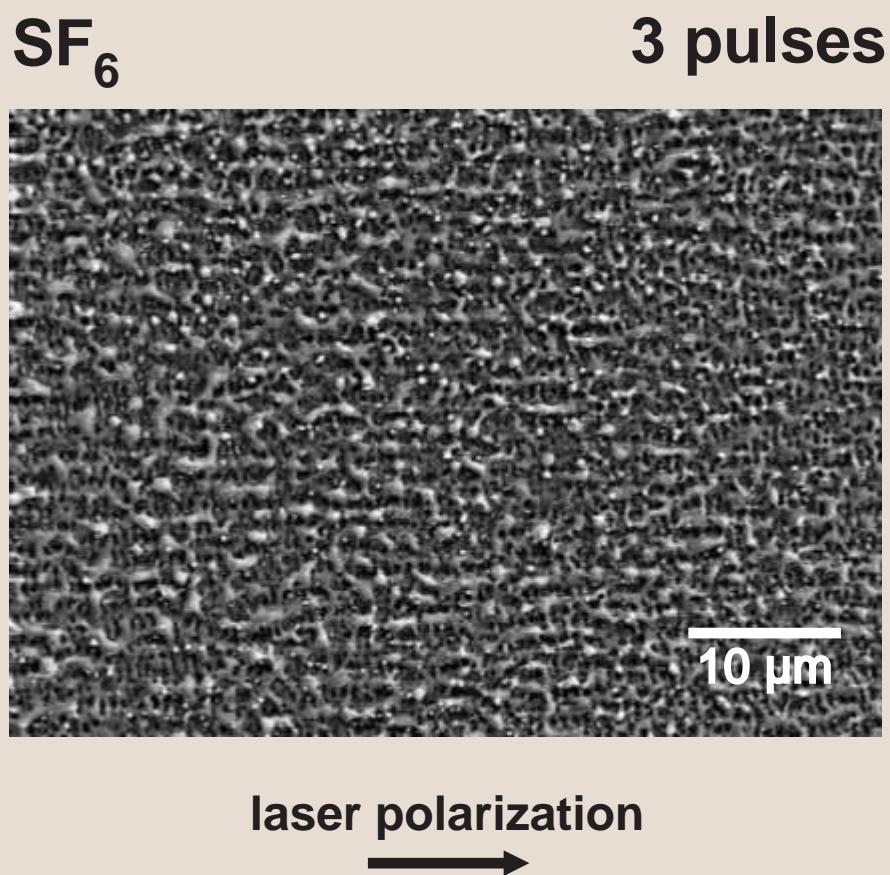
Vary number of laser pulses

Calculate Fourier transform of image

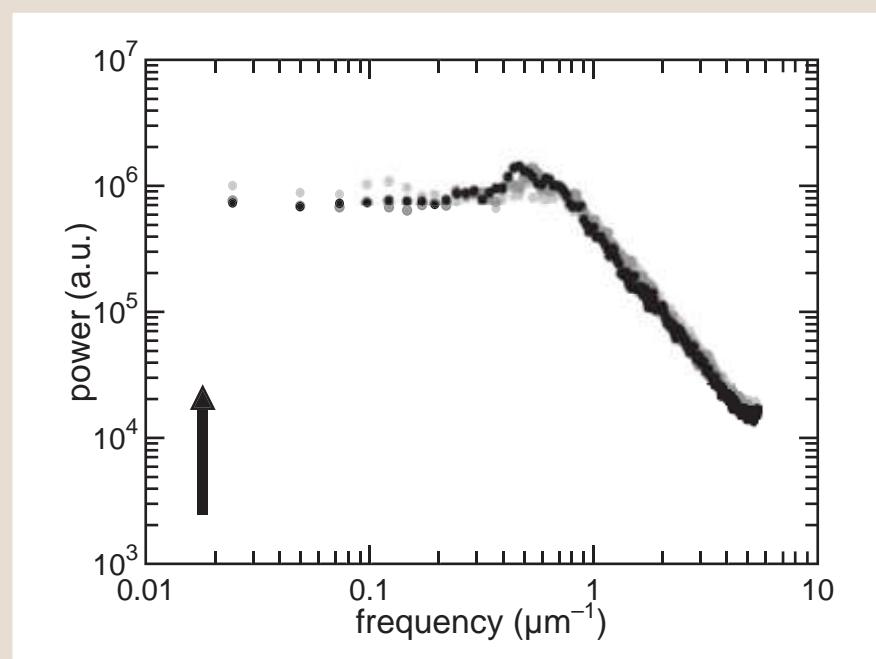
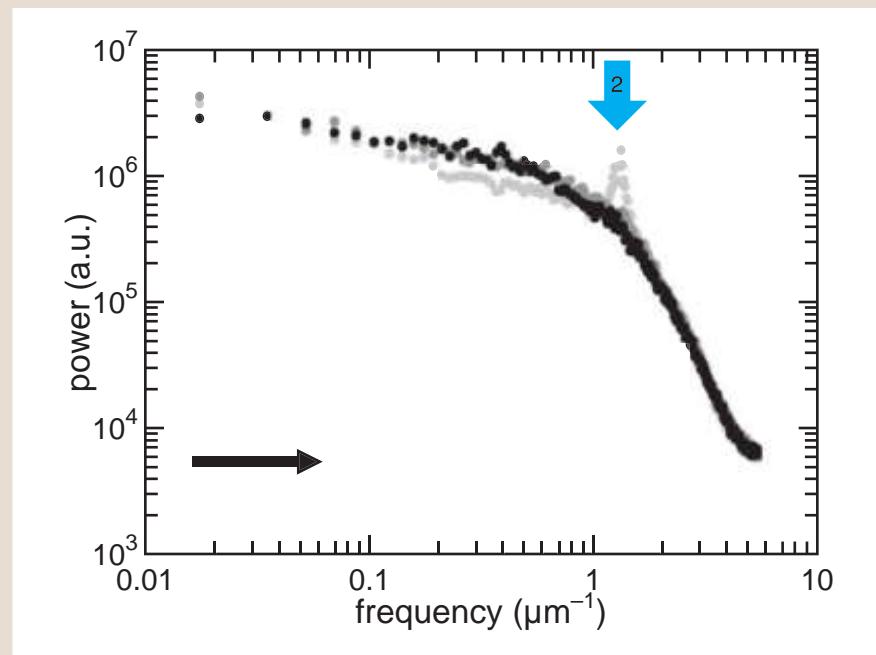
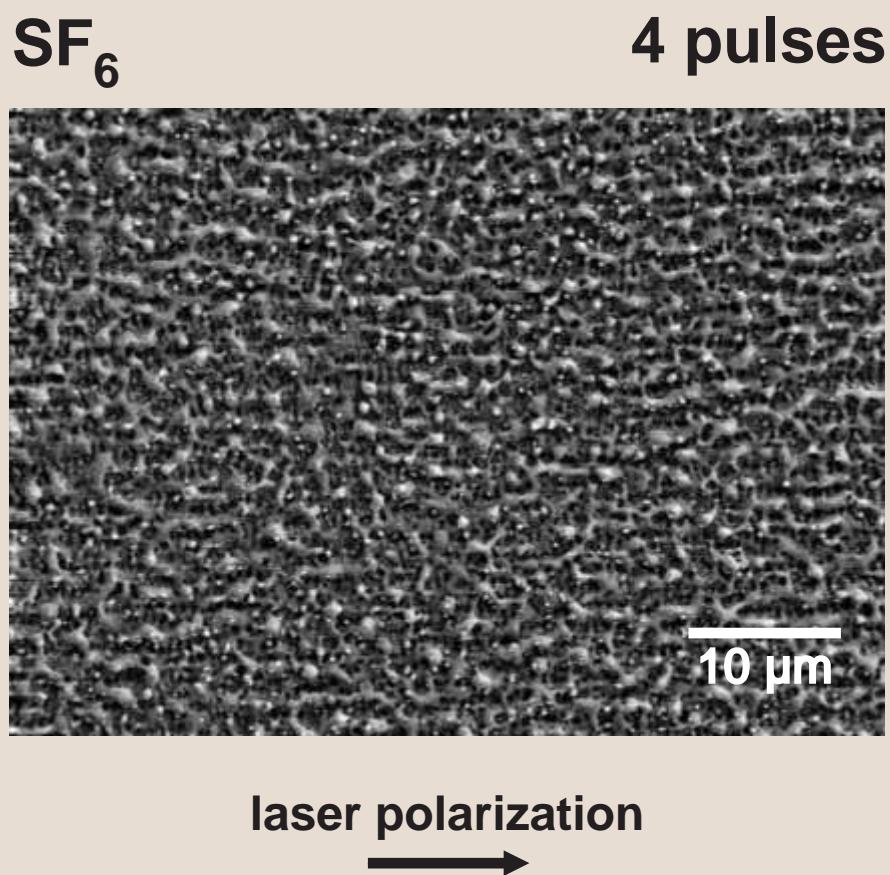
Microspike development



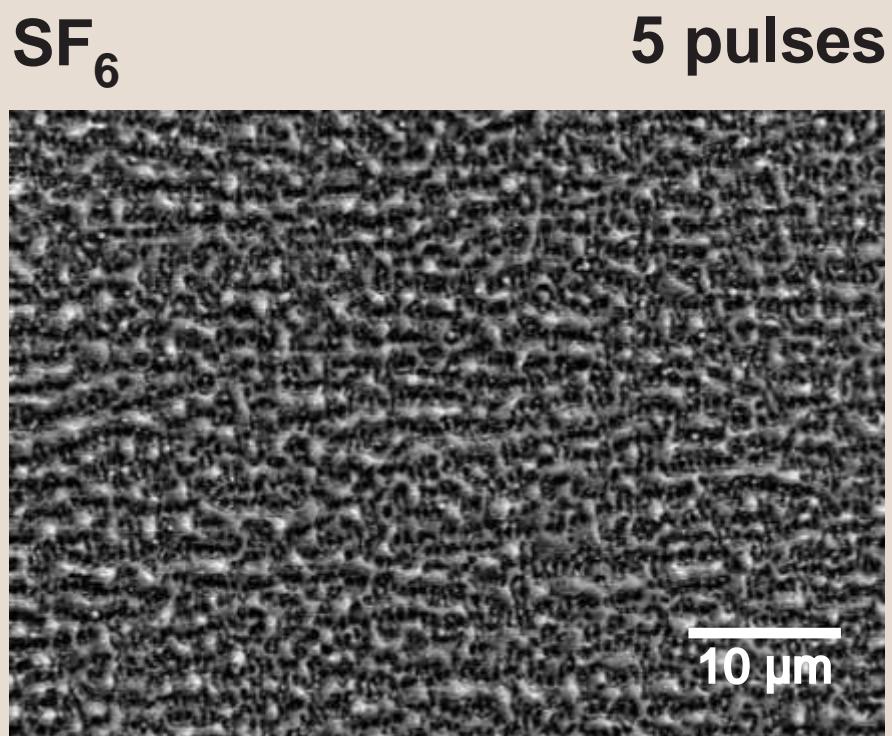
Microspike development



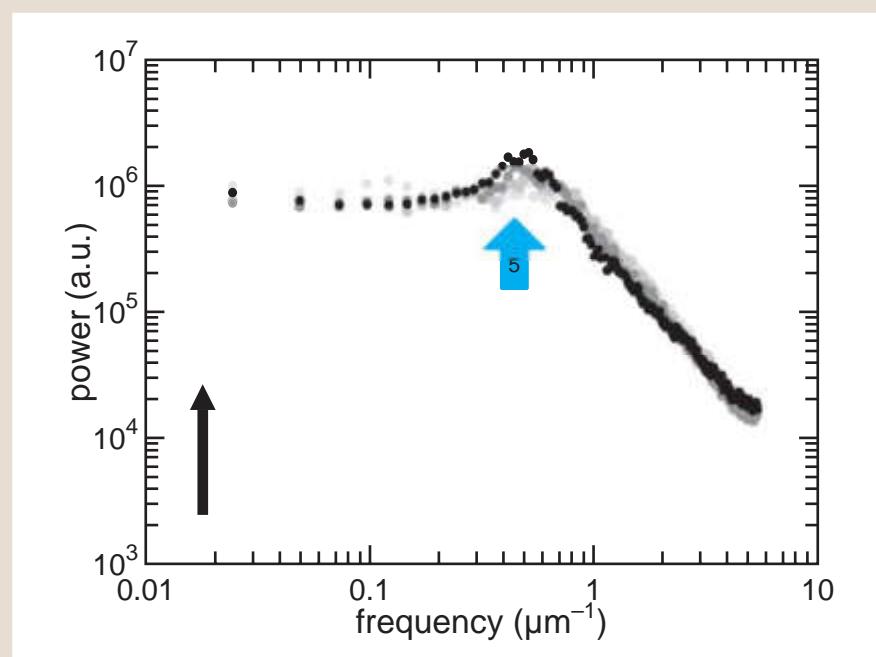
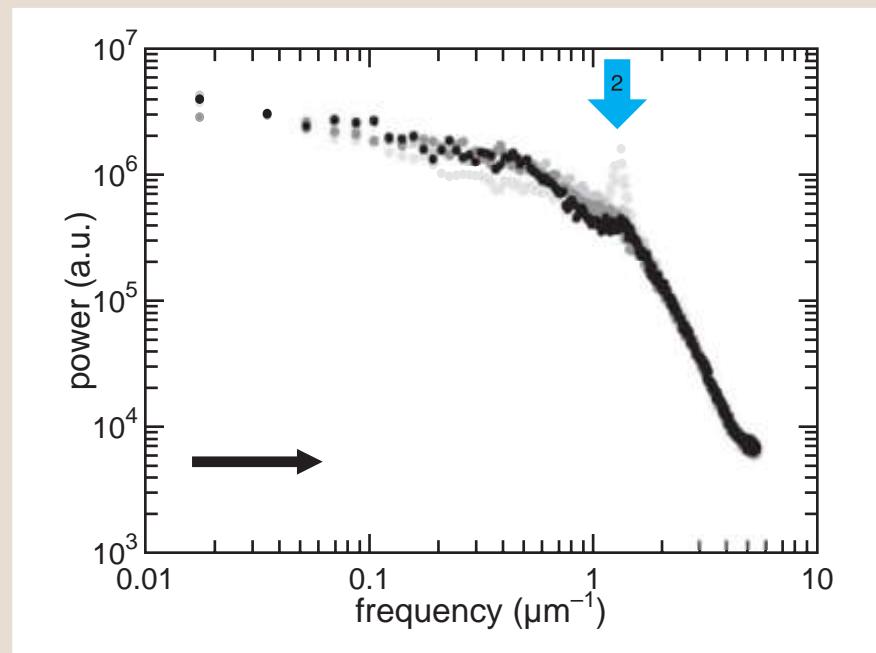
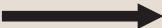
Microspike development



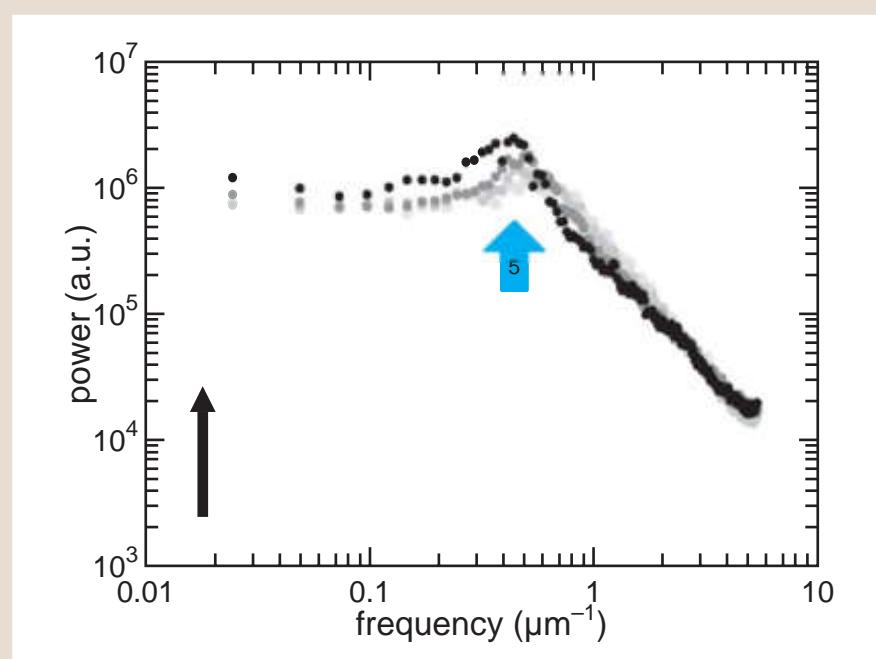
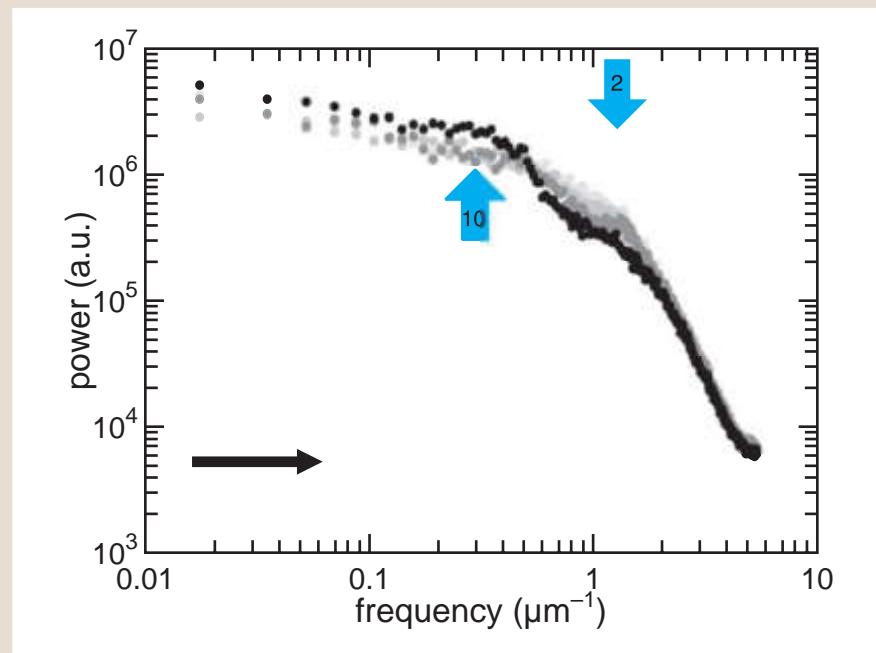
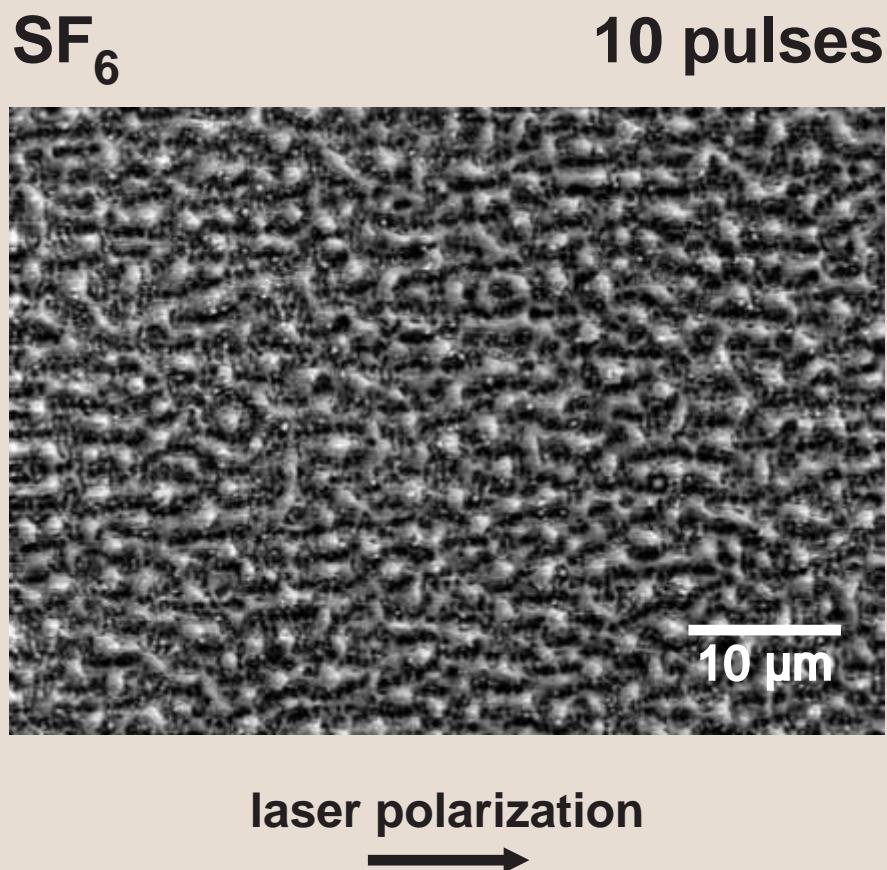
Microspike development



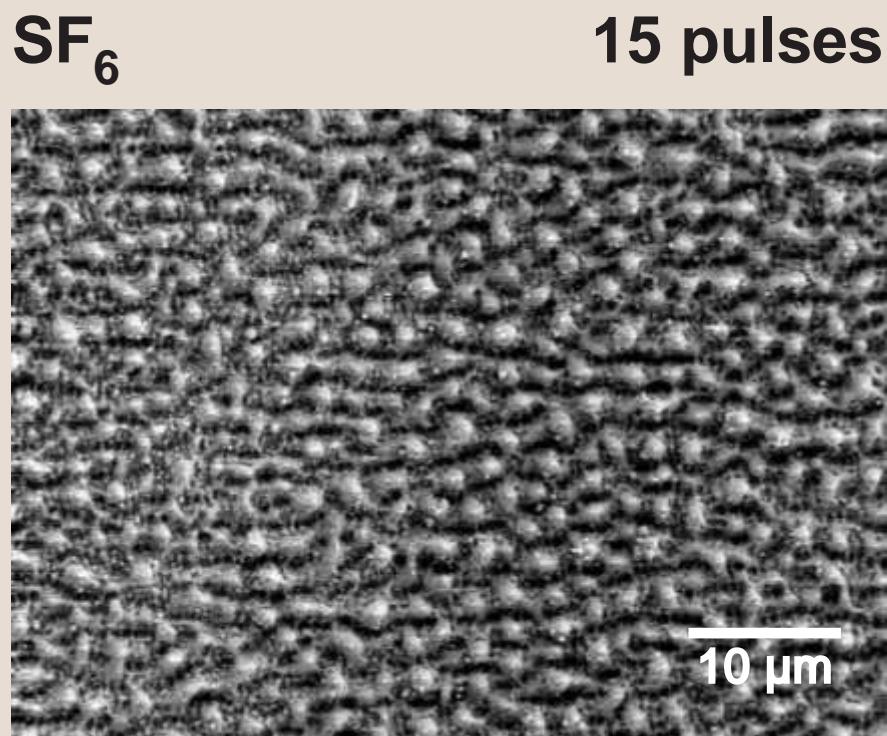
laser polarization



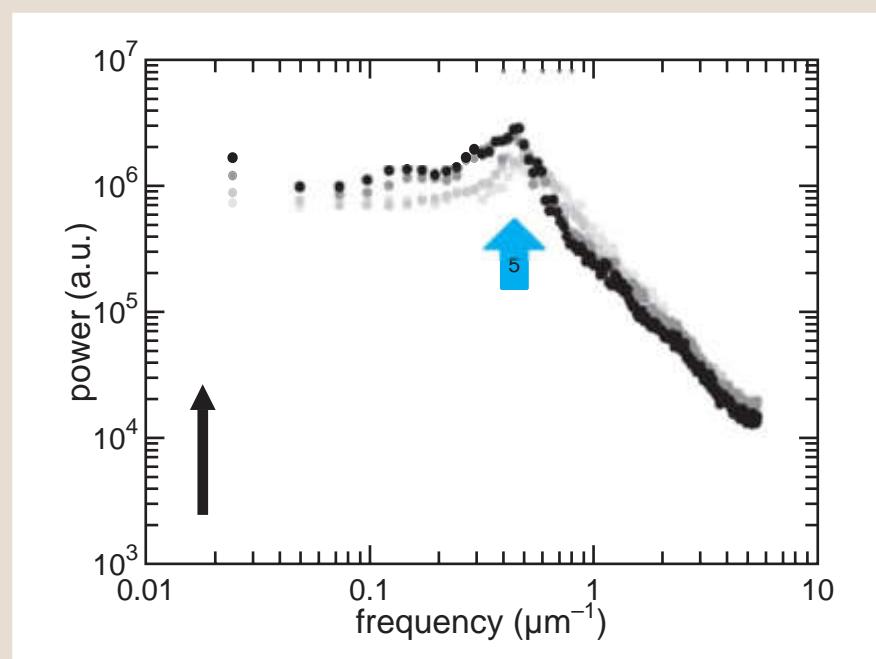
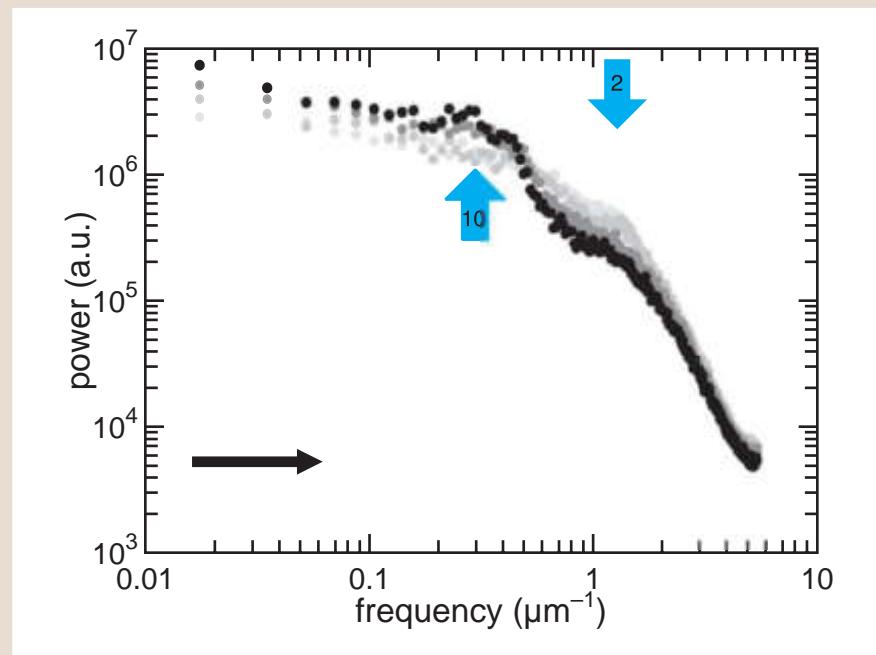
Microspike development



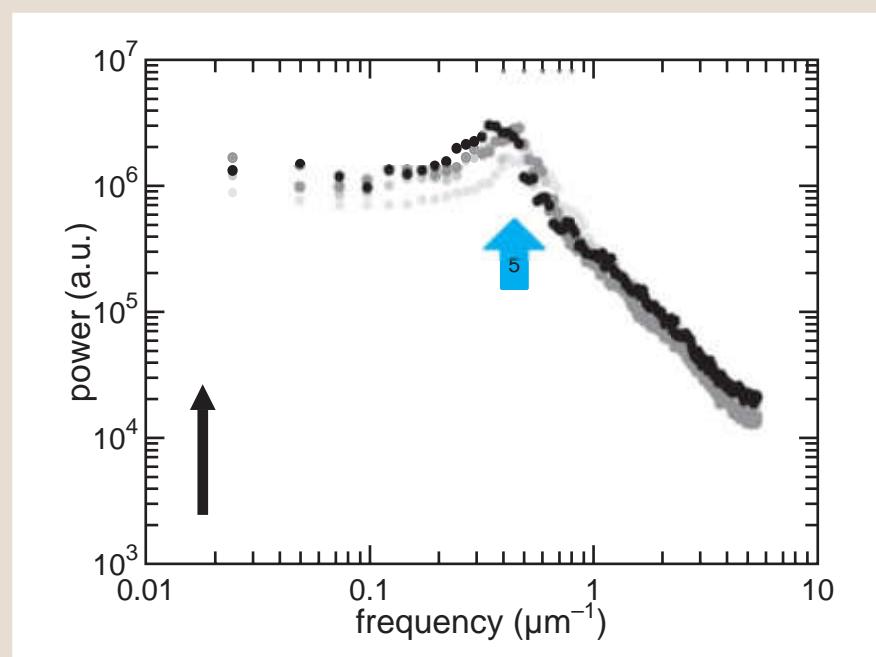
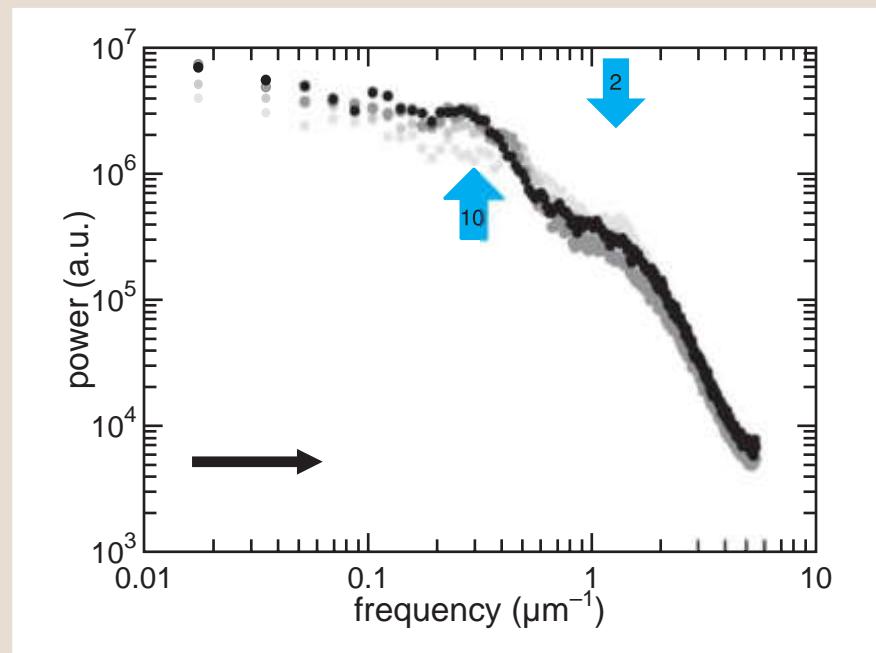
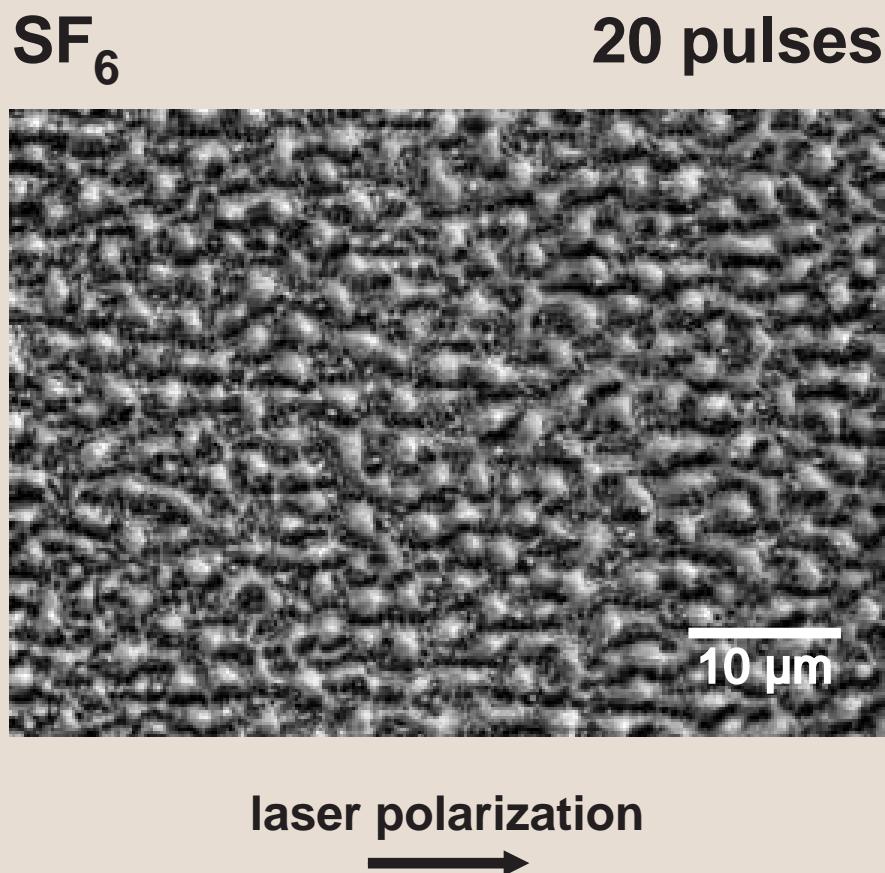
Microspike development



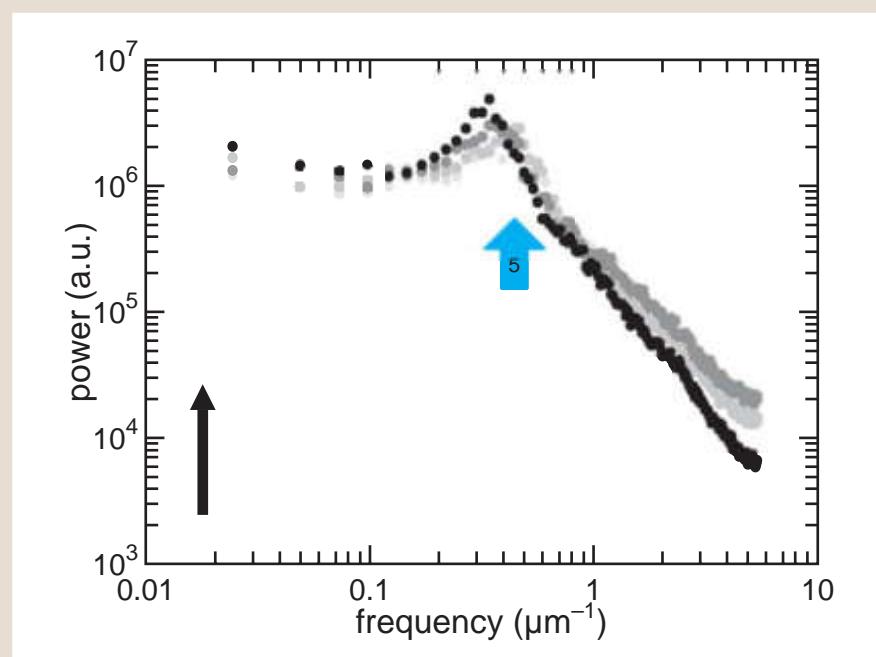
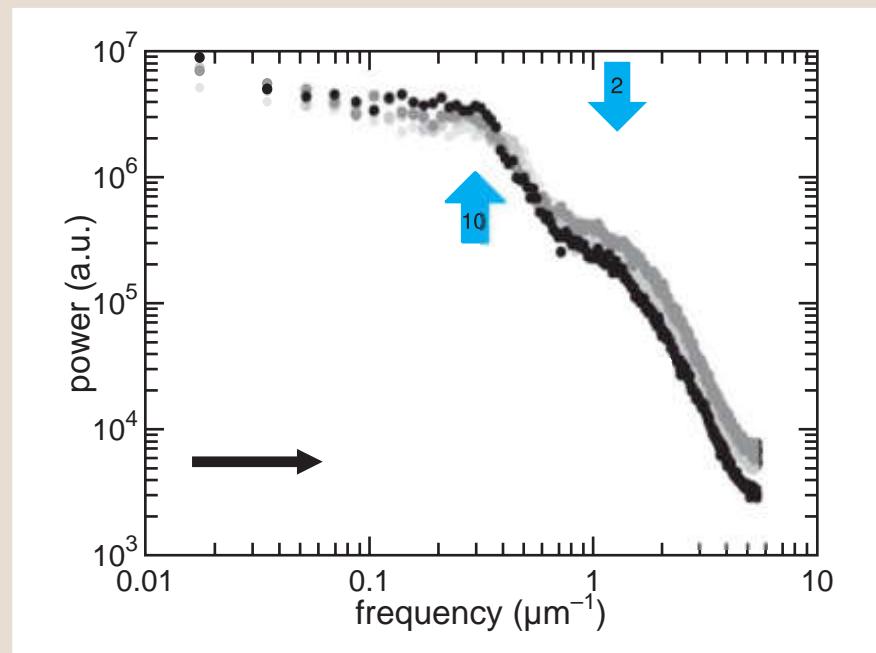
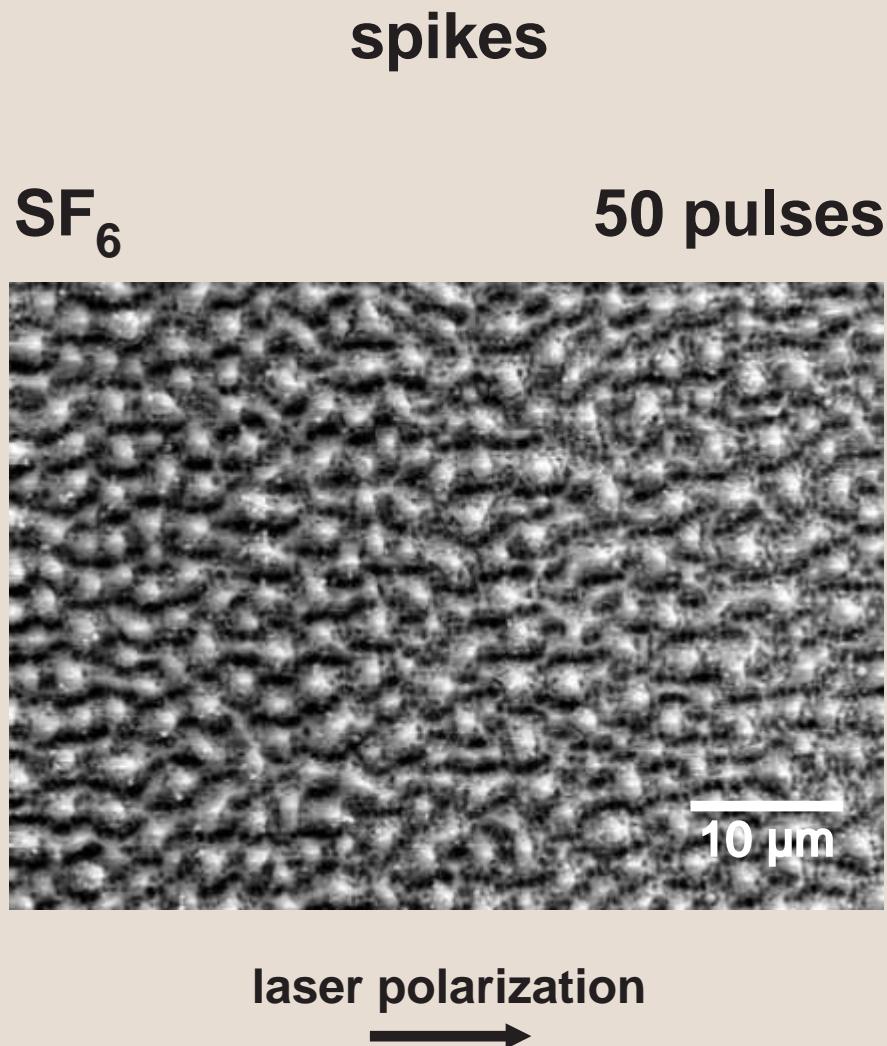
laser polarization
→



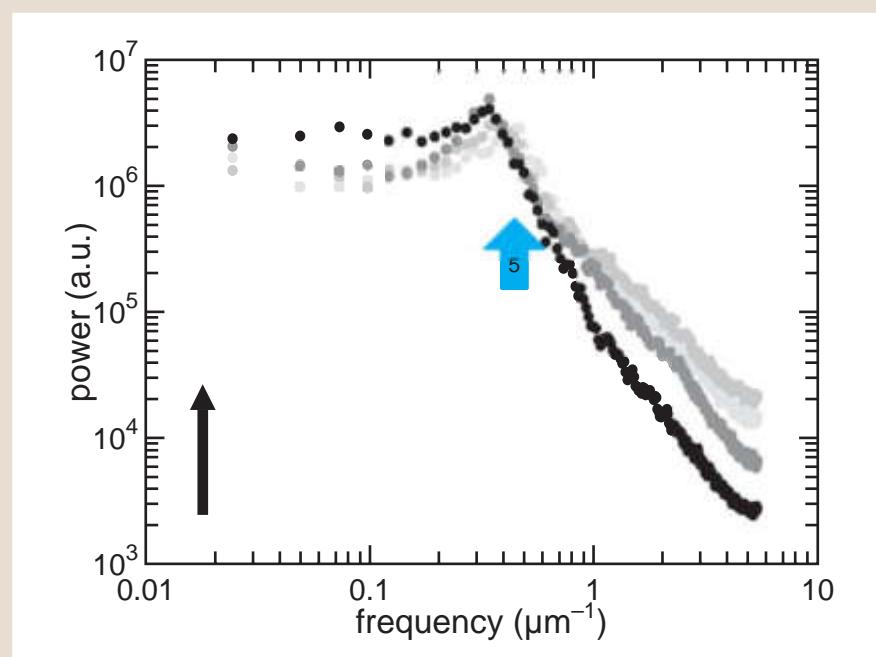
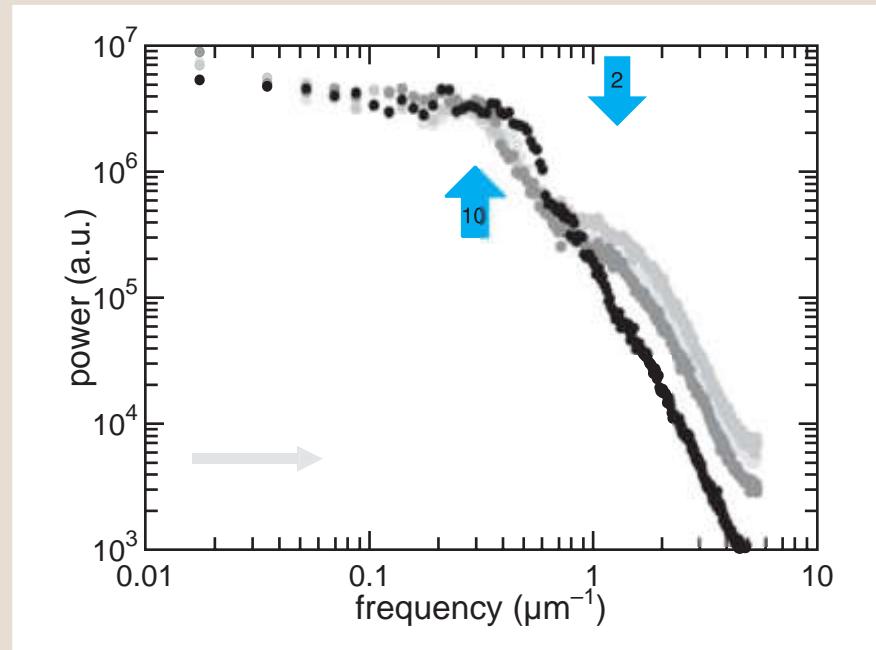
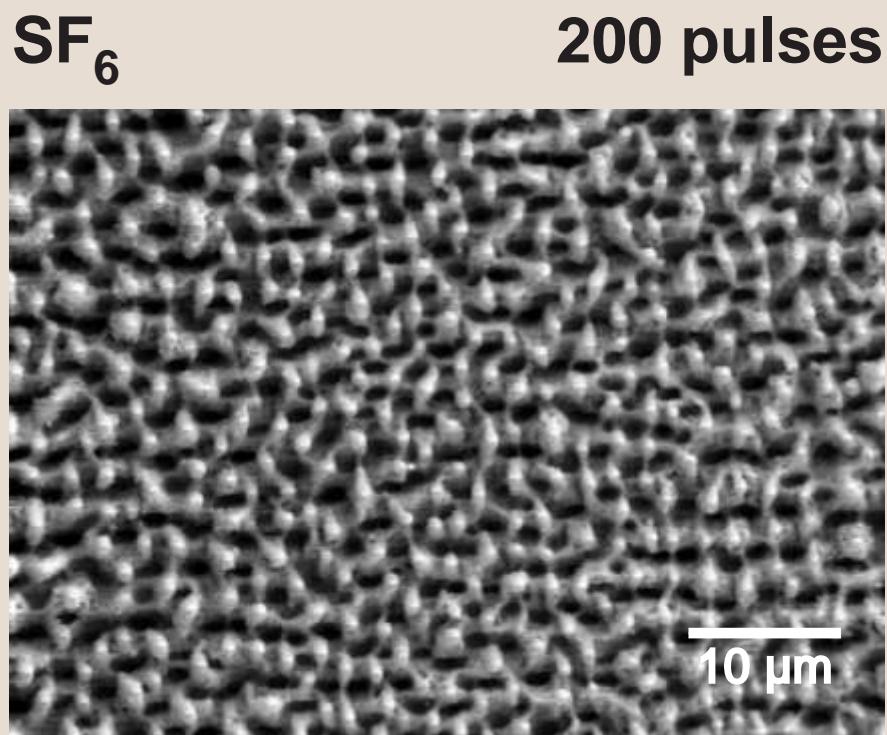
Microspike development



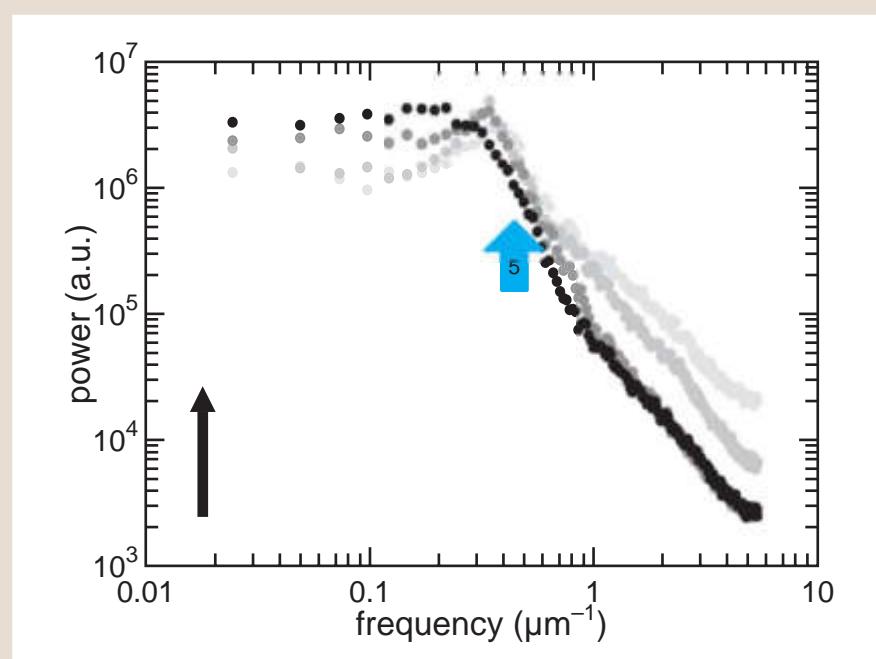
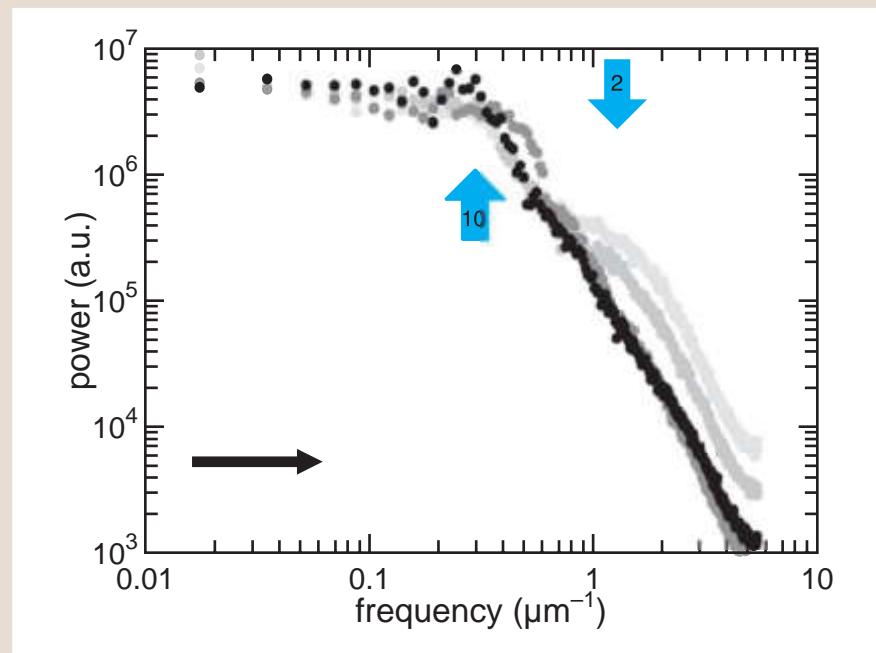
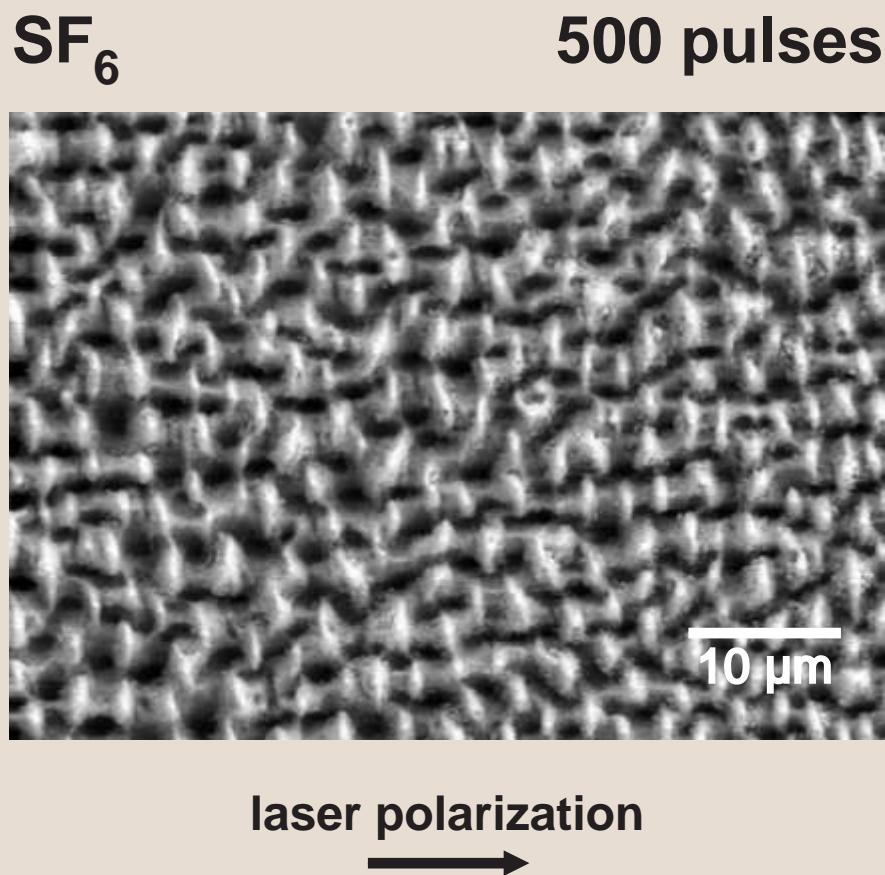
Microspike development



Microspike development

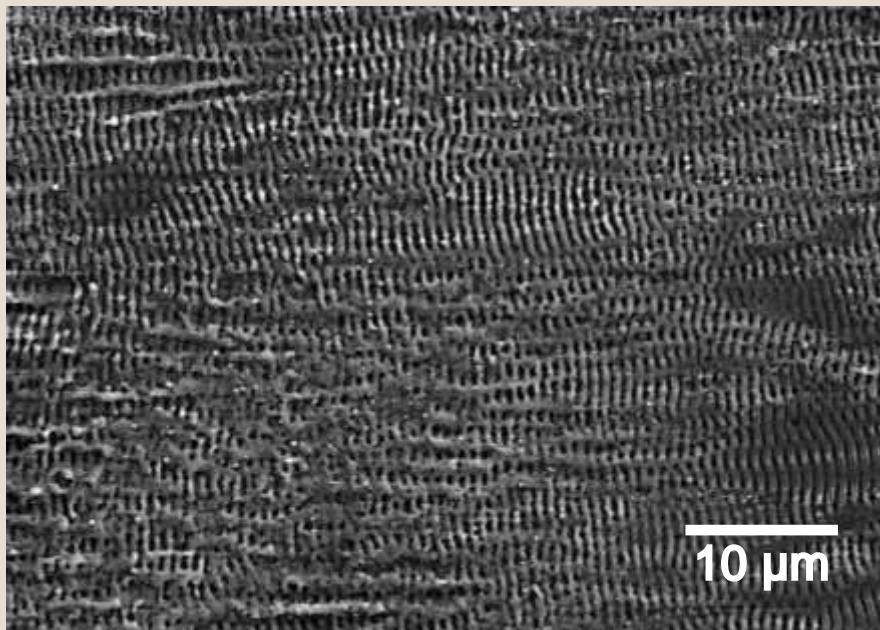


Microspike development

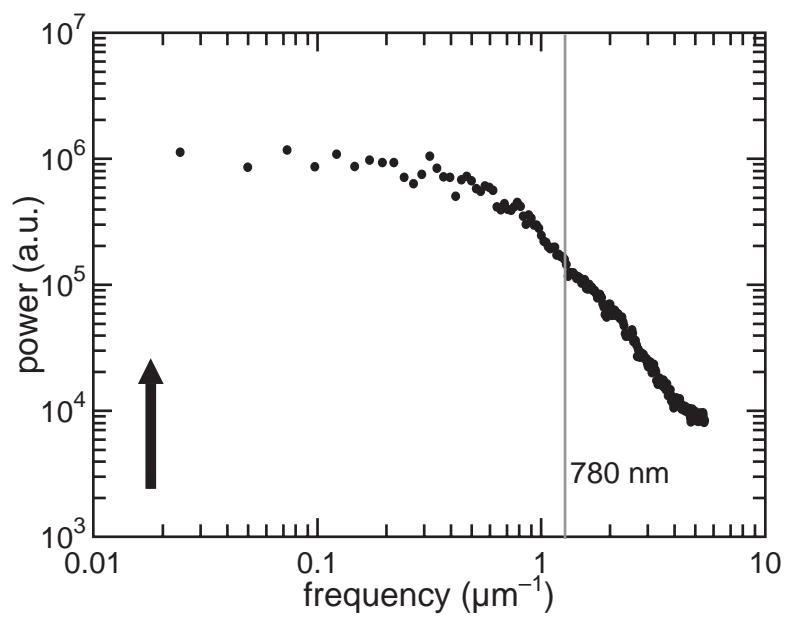
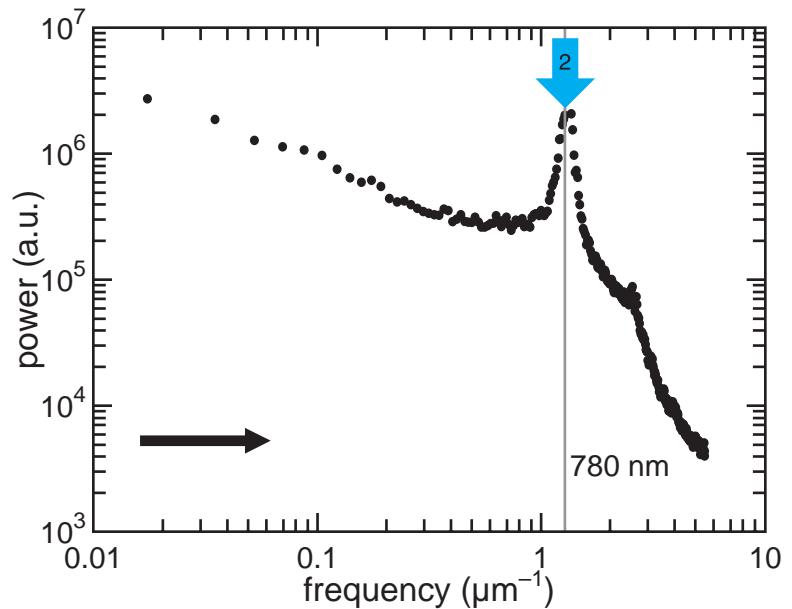


Microspike development

ripples
vacuum 2 pulses



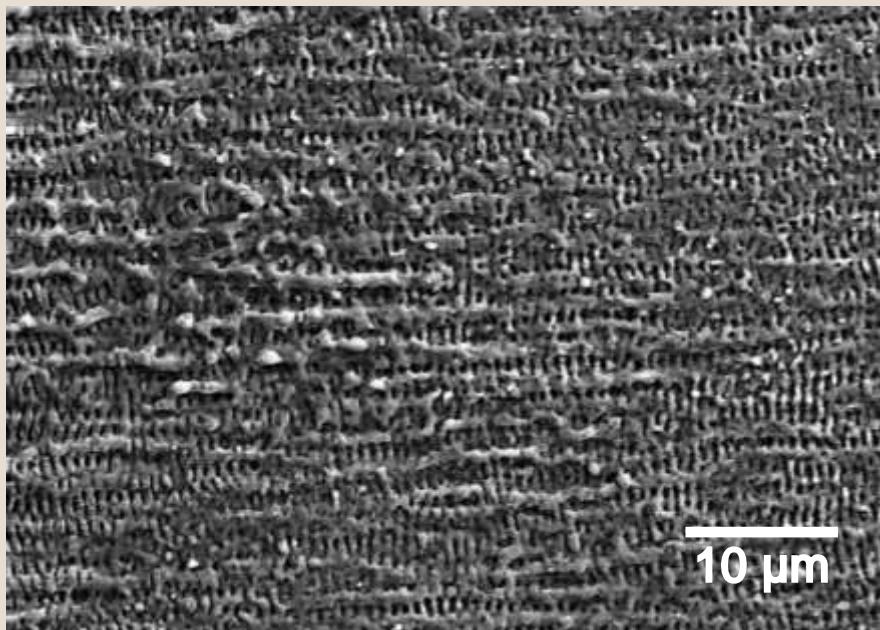
laser polarization
→



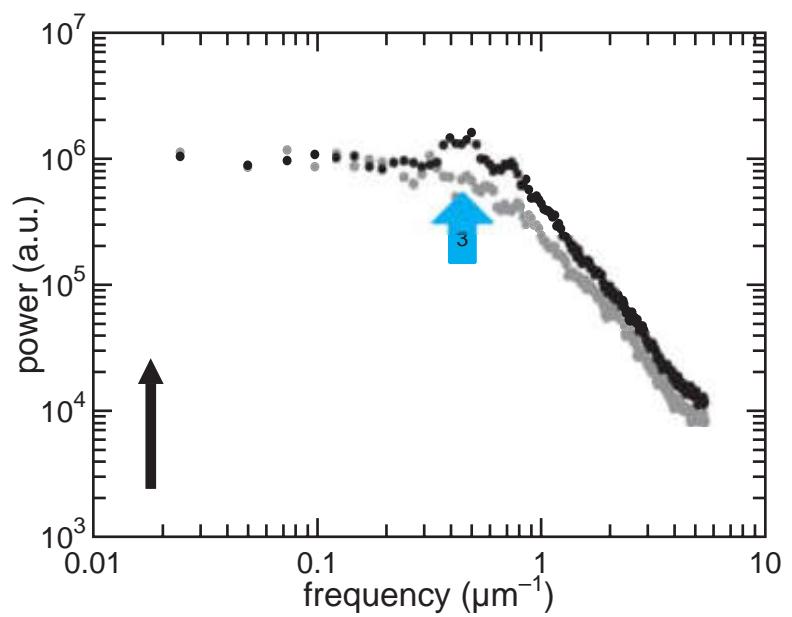
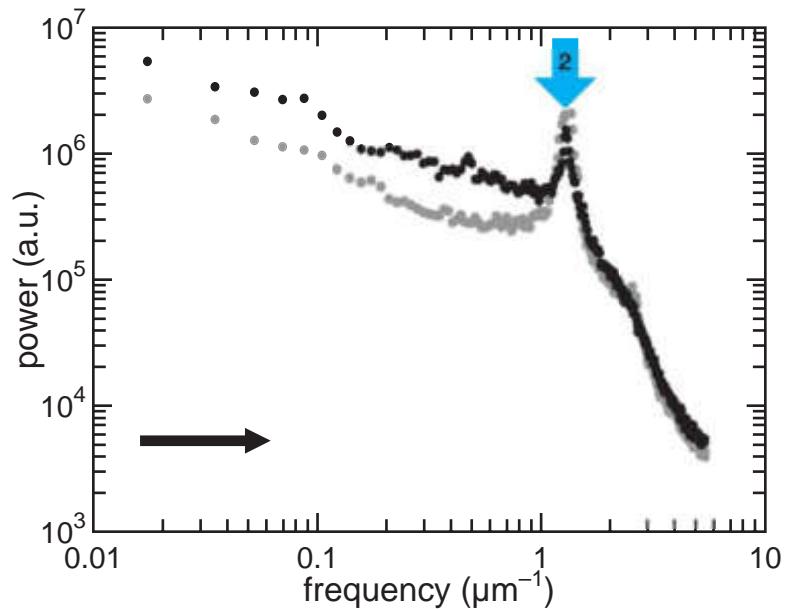
Microspike development

vacuum

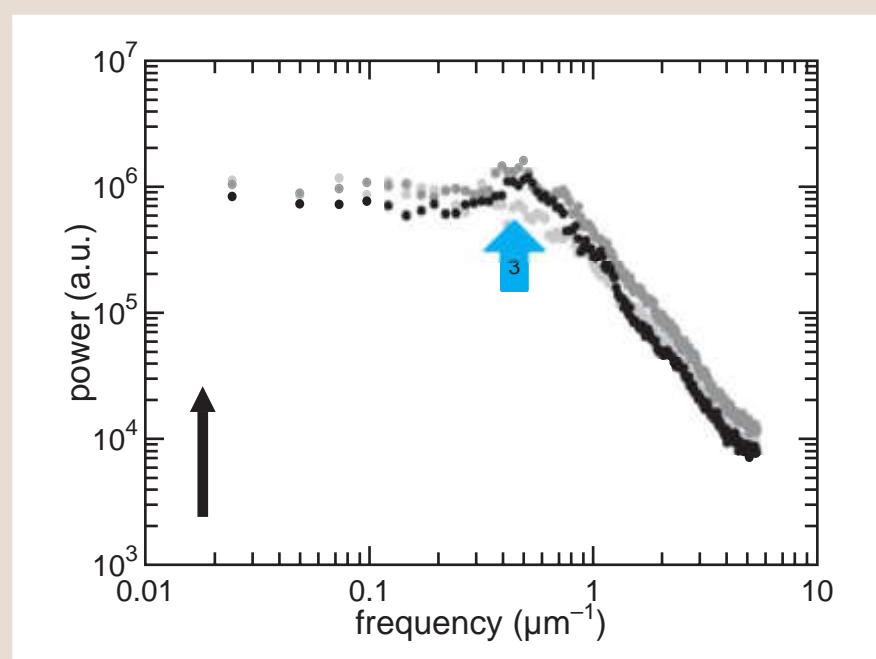
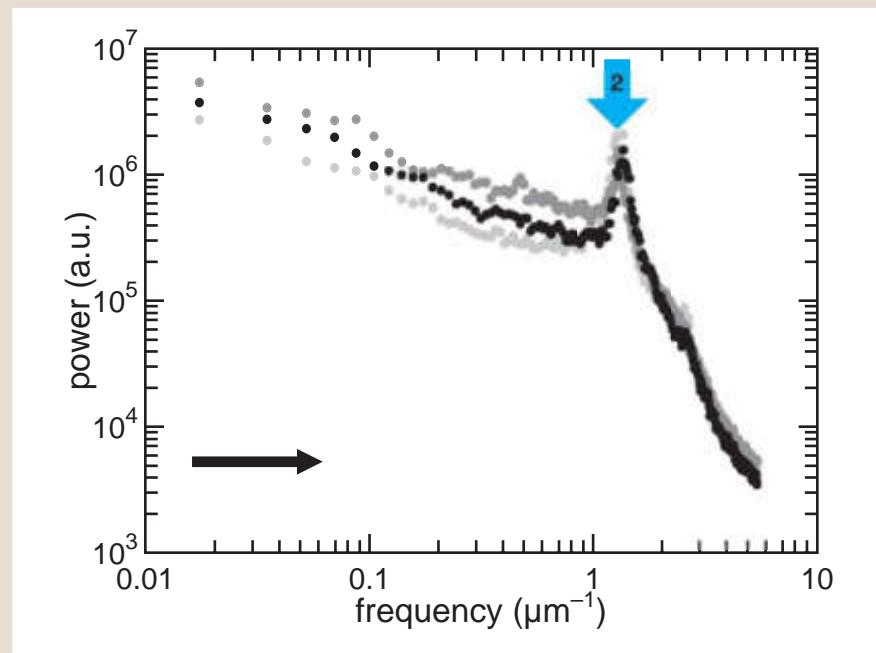
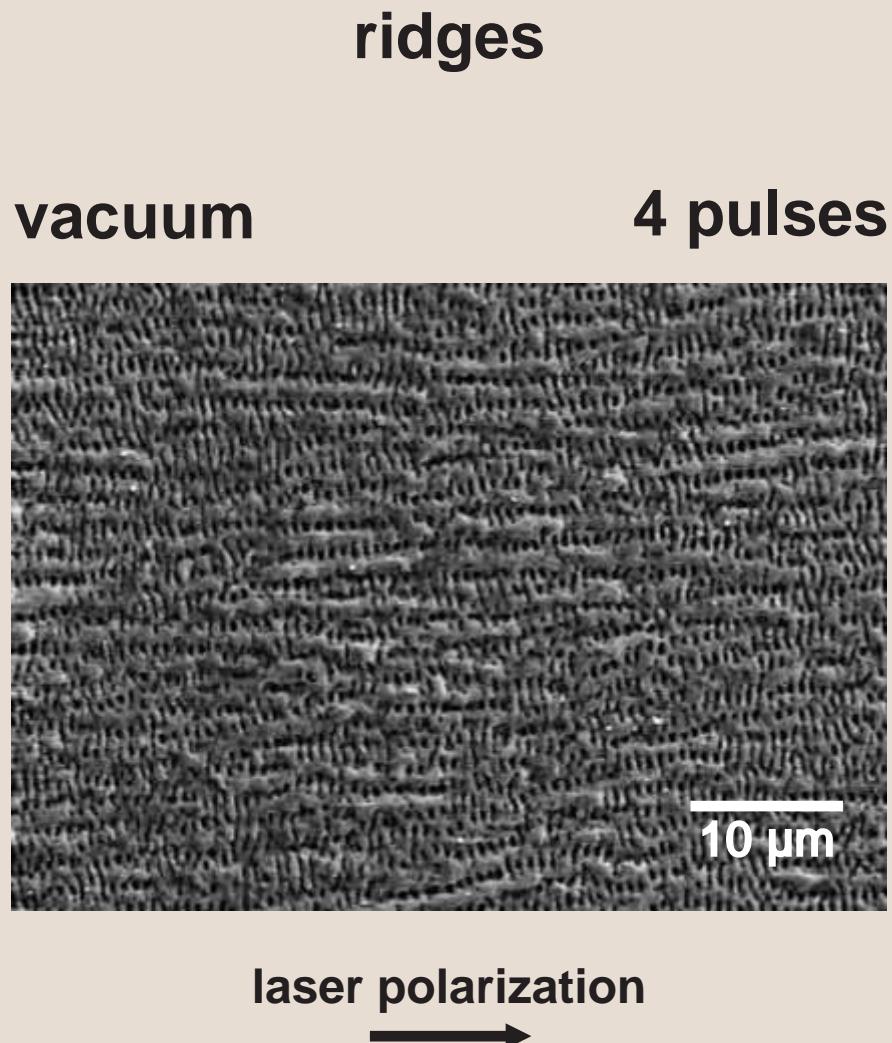
3 pulses



laser polarization
→



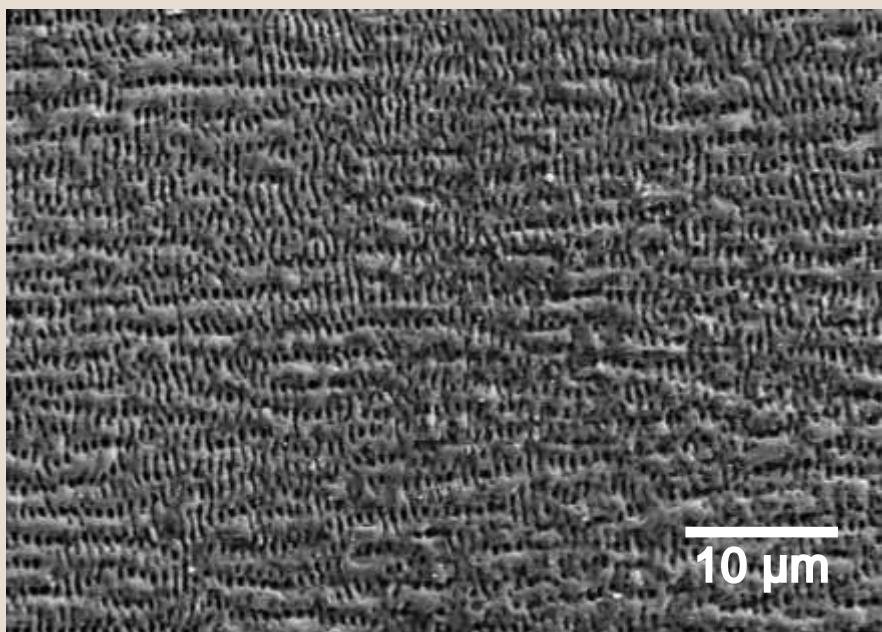
Microspike development



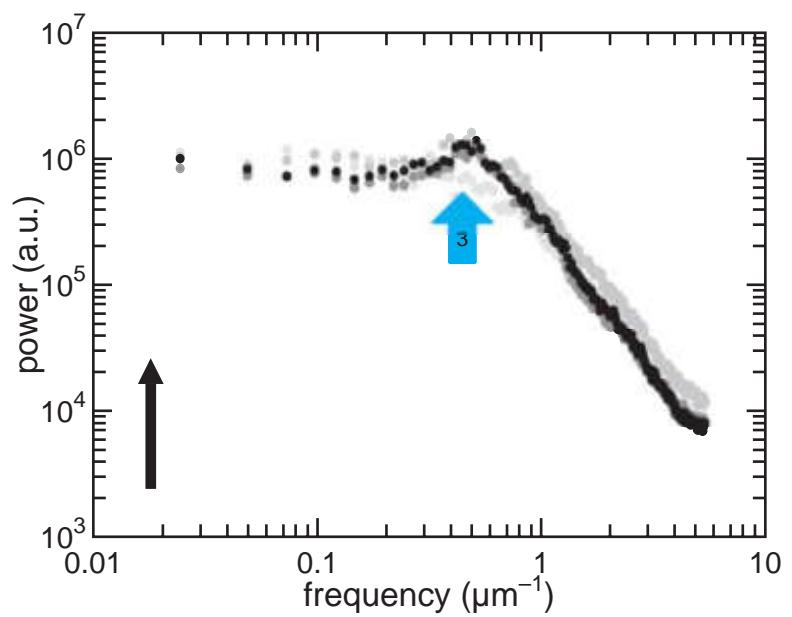
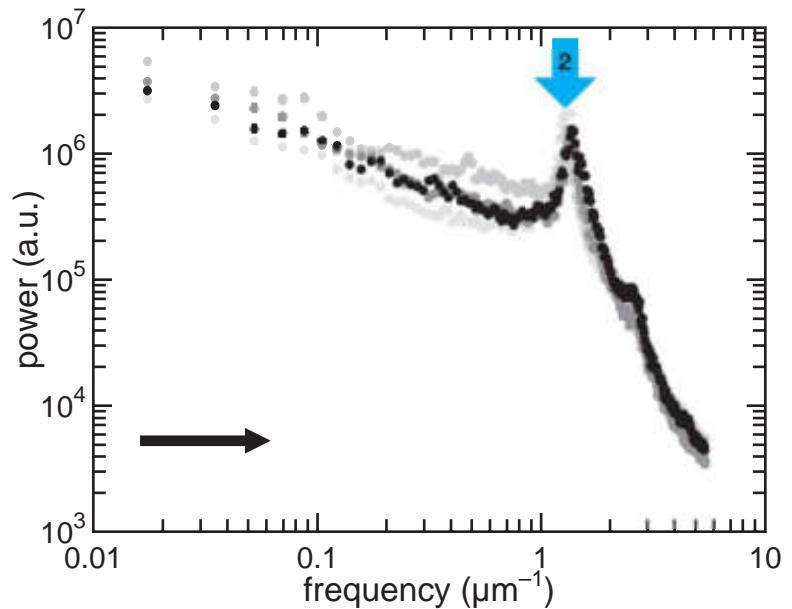
Microspike development

vacuum

5 pulses

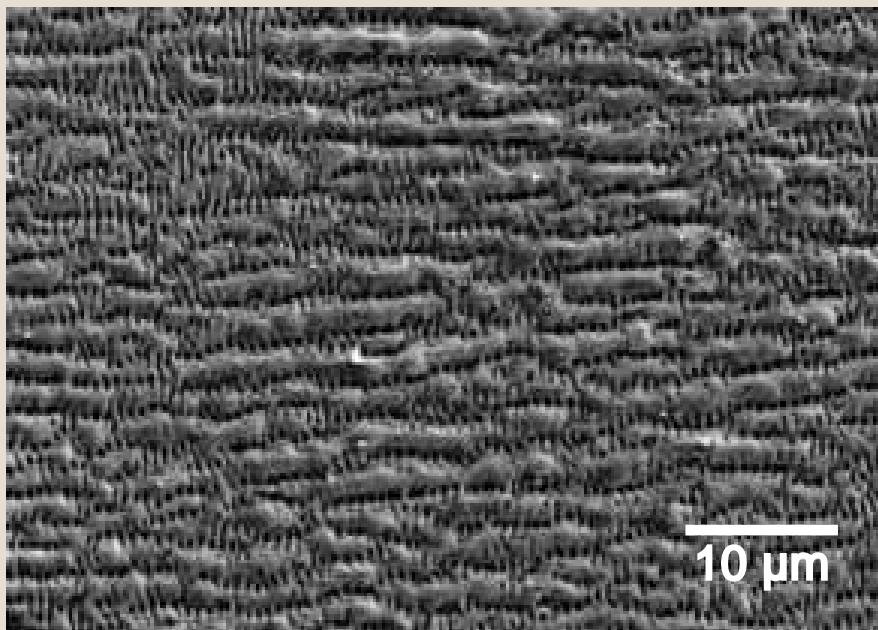


laser polarization
→

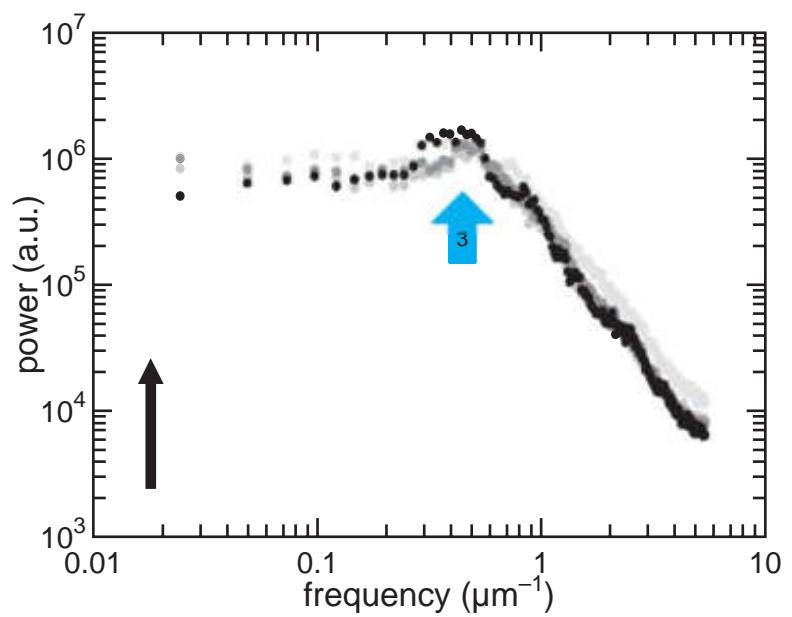
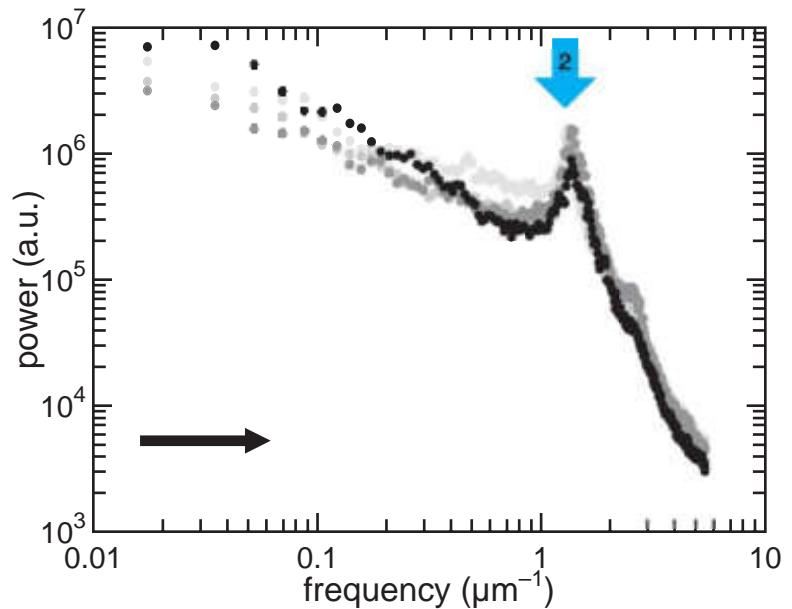


Microspike development

vacuum **10 pulses**



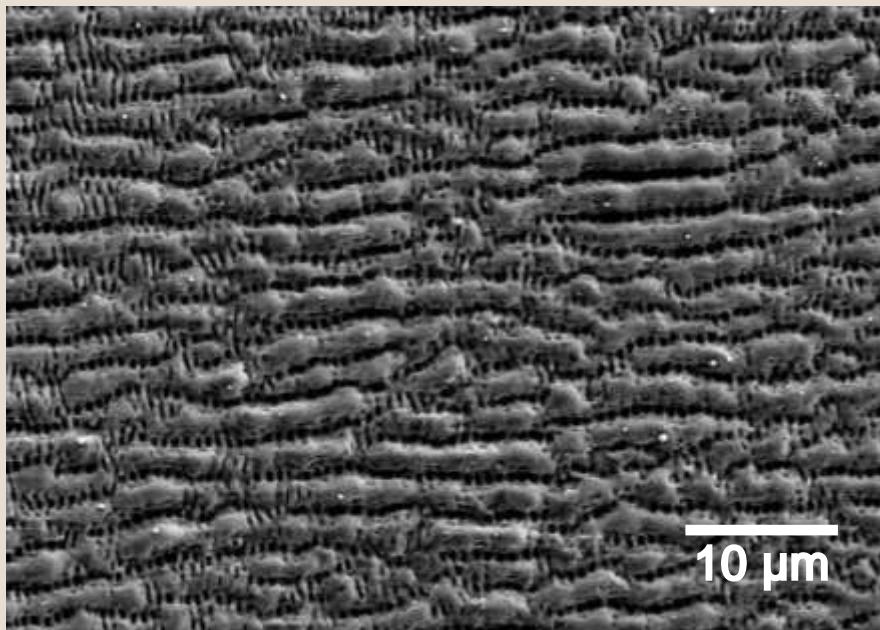
laser polarization
→



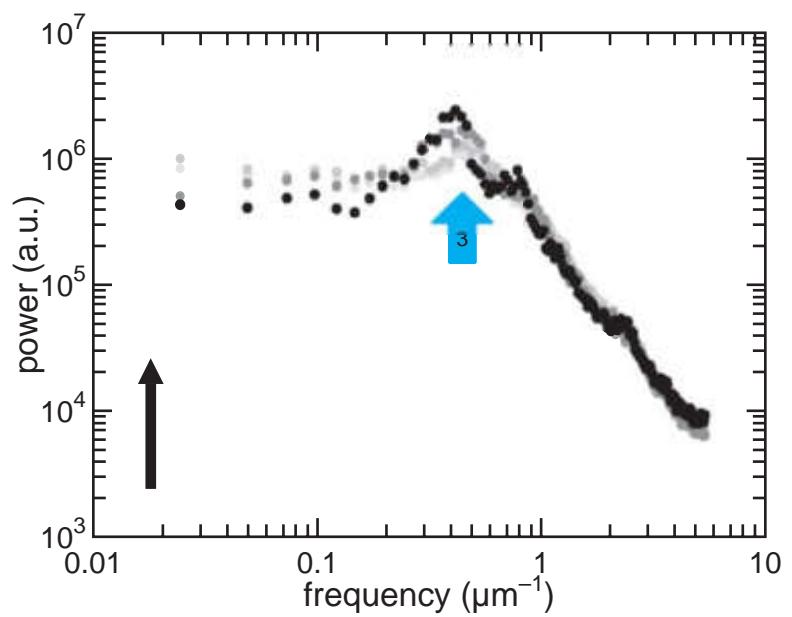
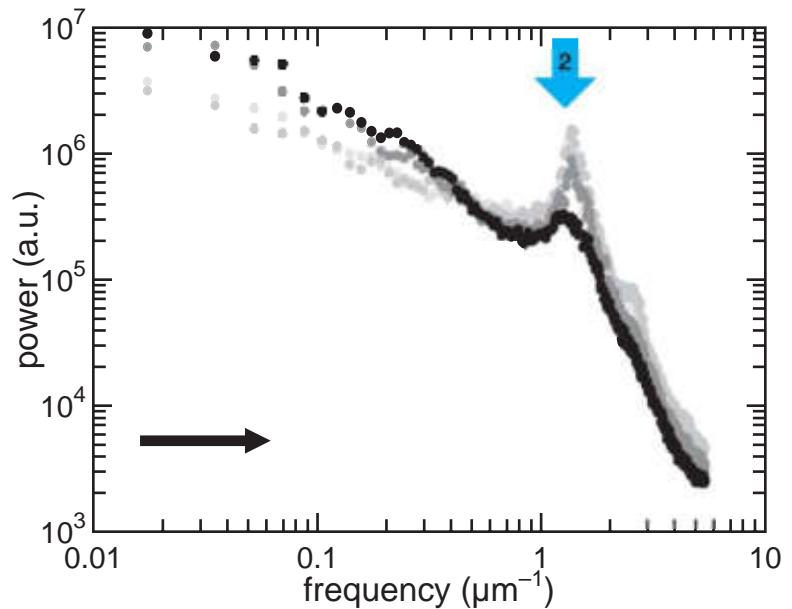
Microspike development

vacuum

15 pulses



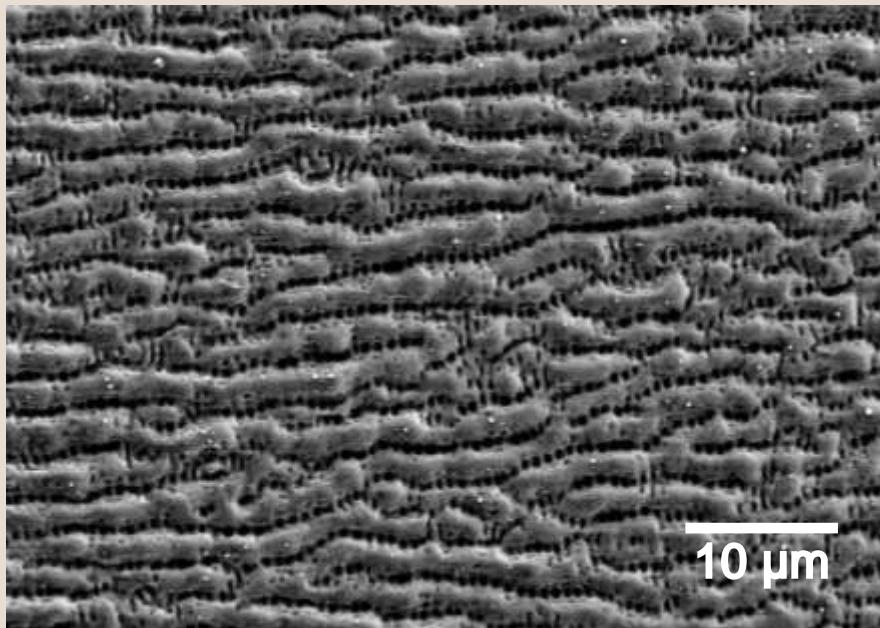
laser polarization
→



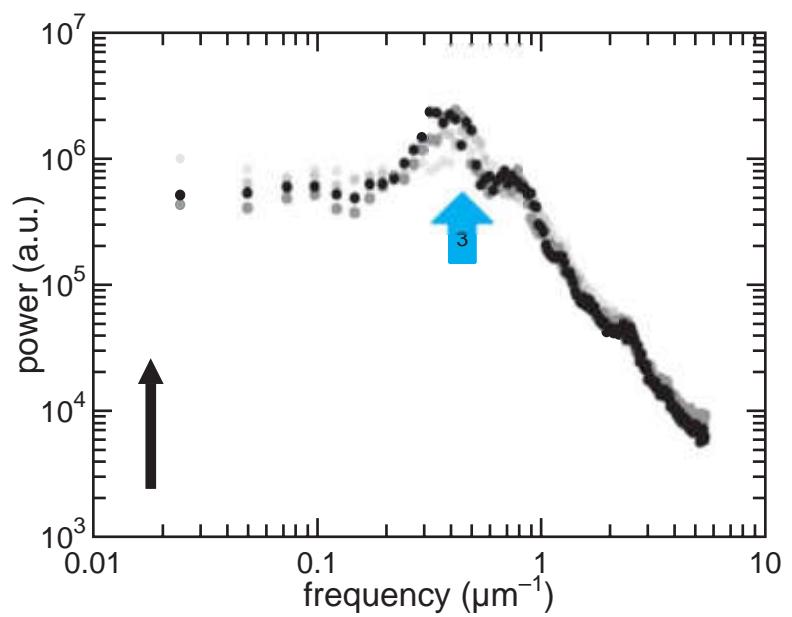
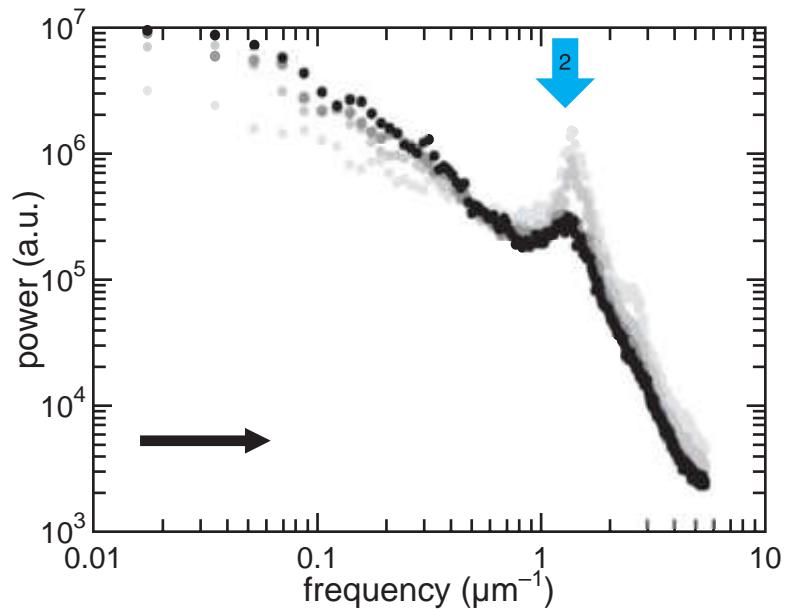
Microspike development

vacuum

20 pulses

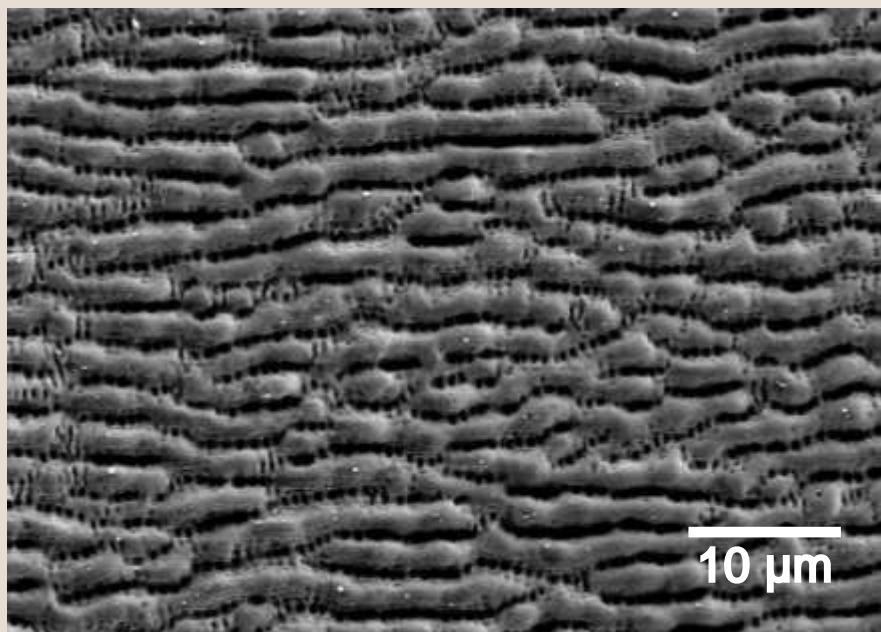


laser polarization
→

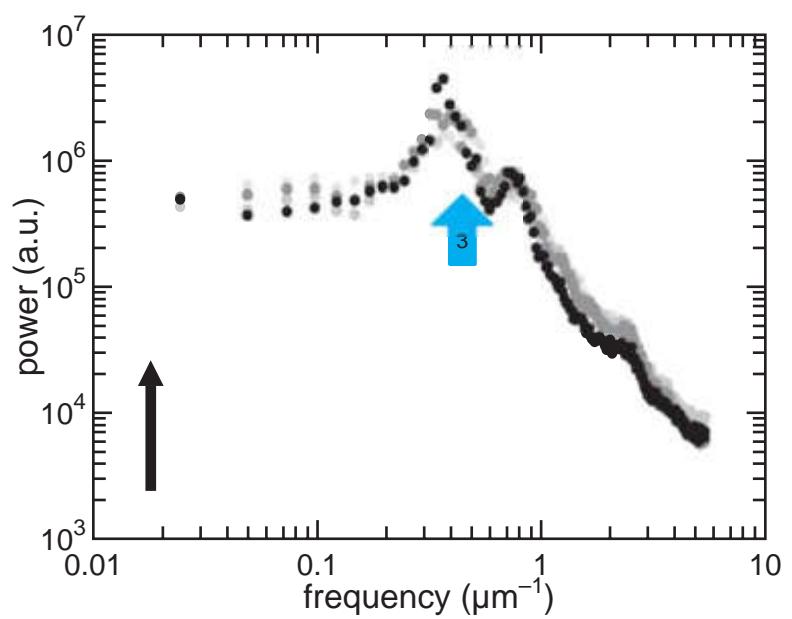
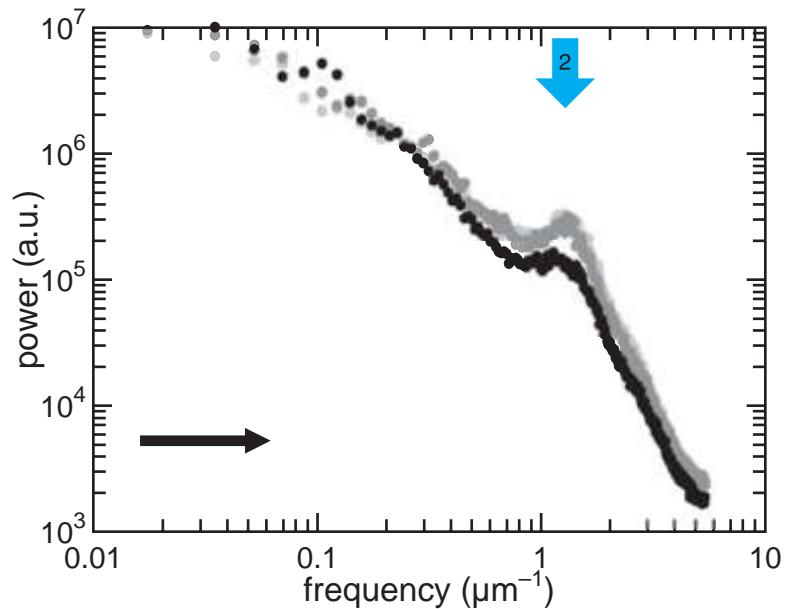


Microspike development

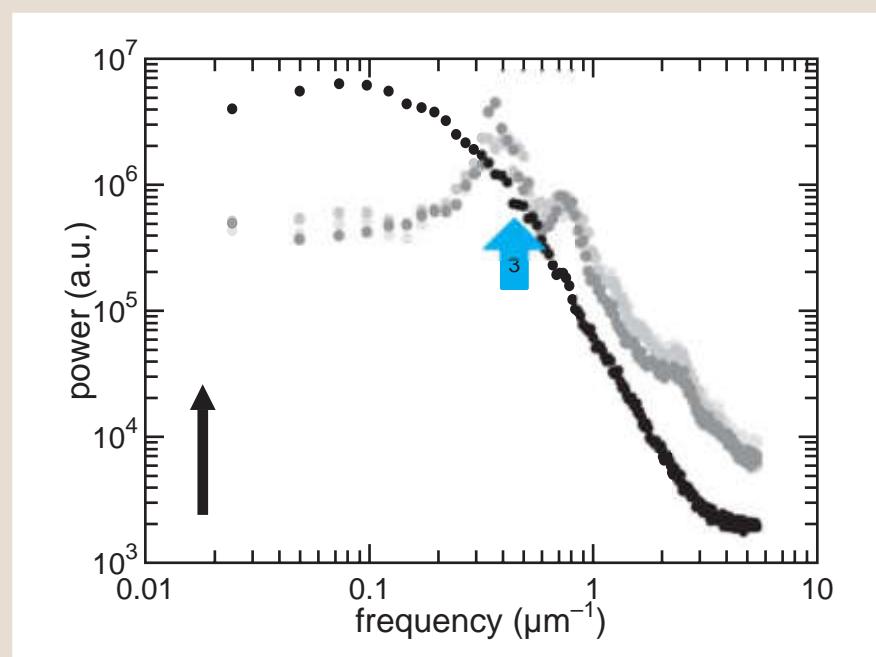
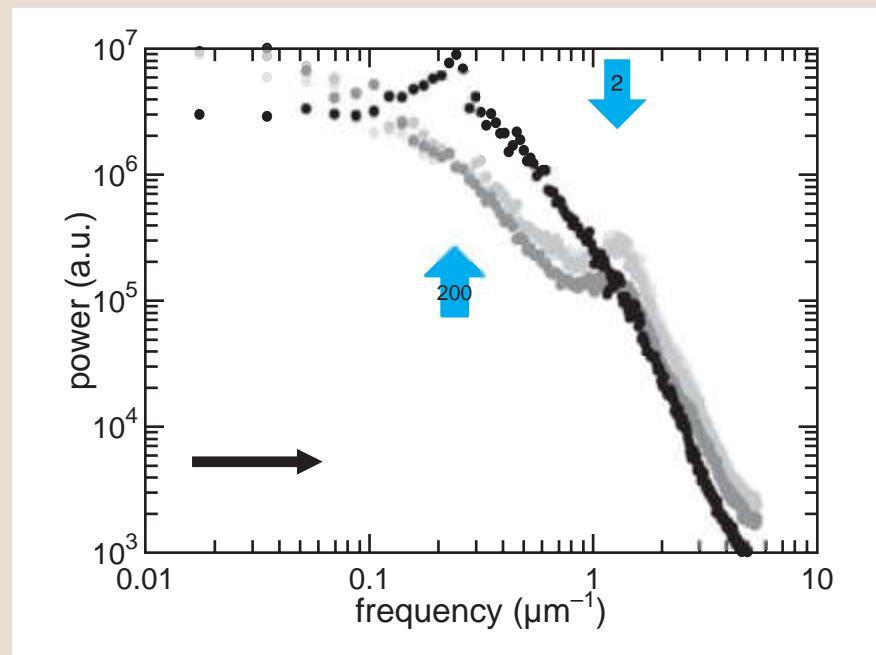
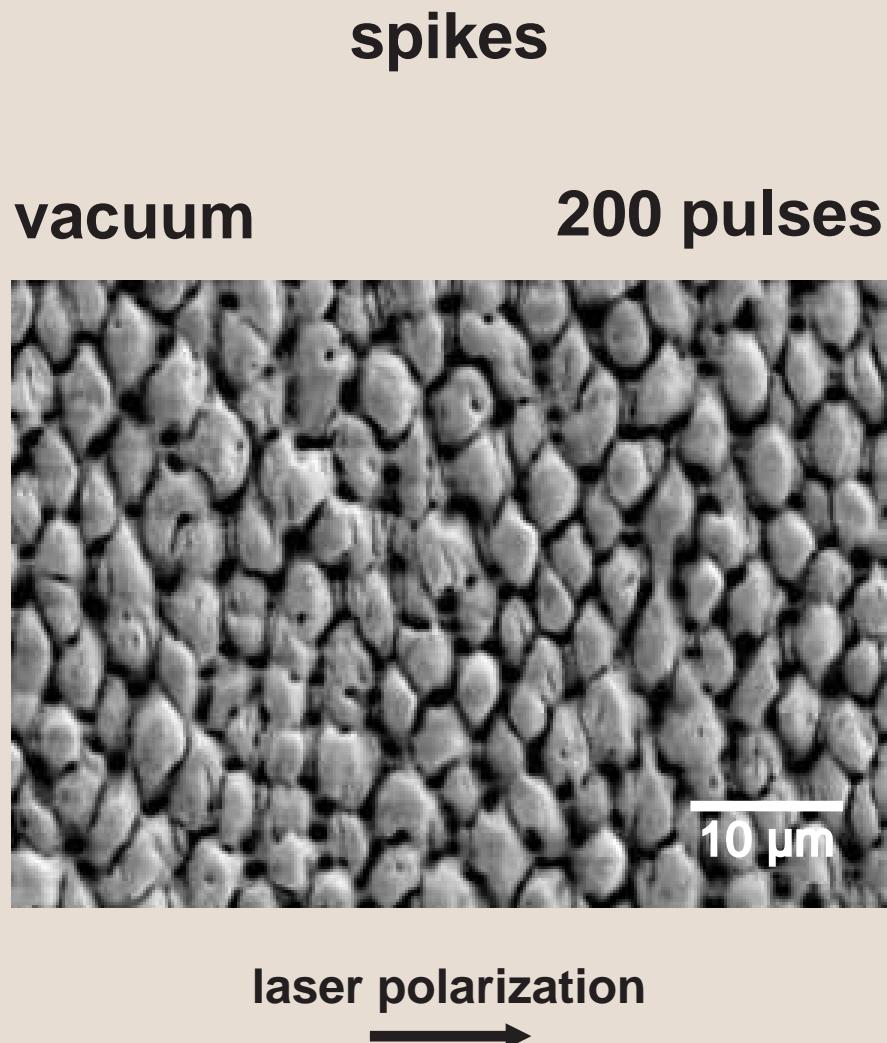
vacuum **50 pulses**



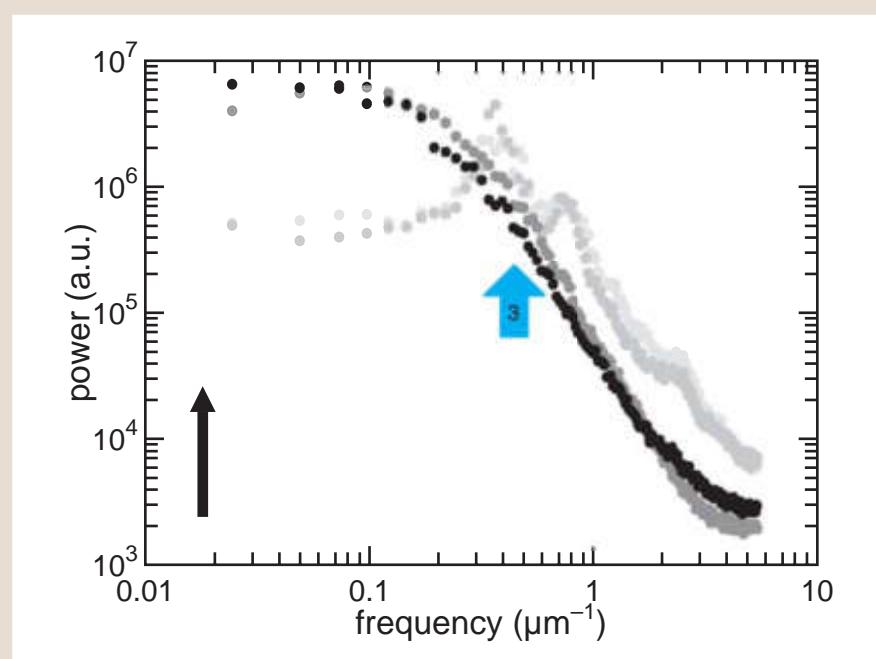
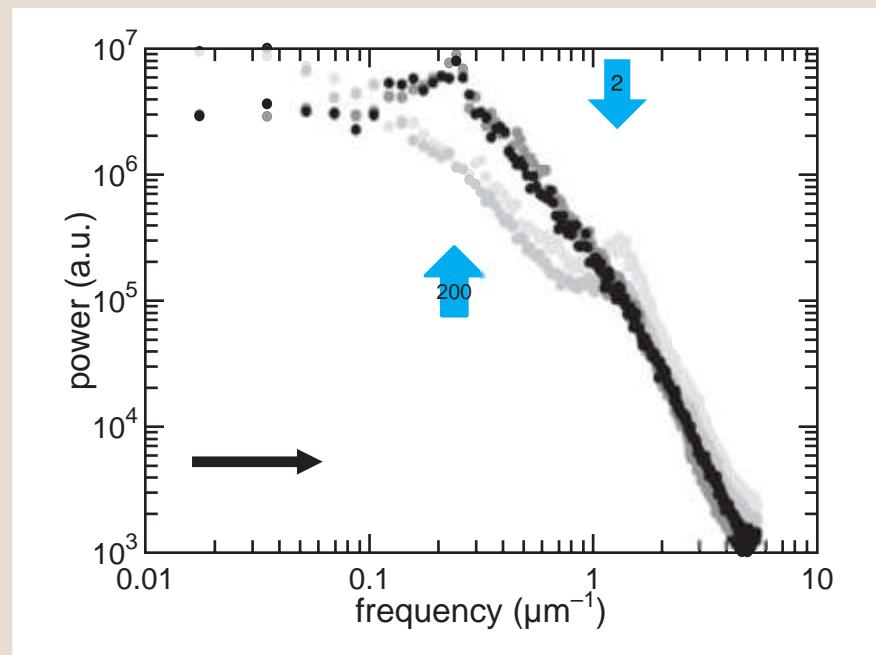
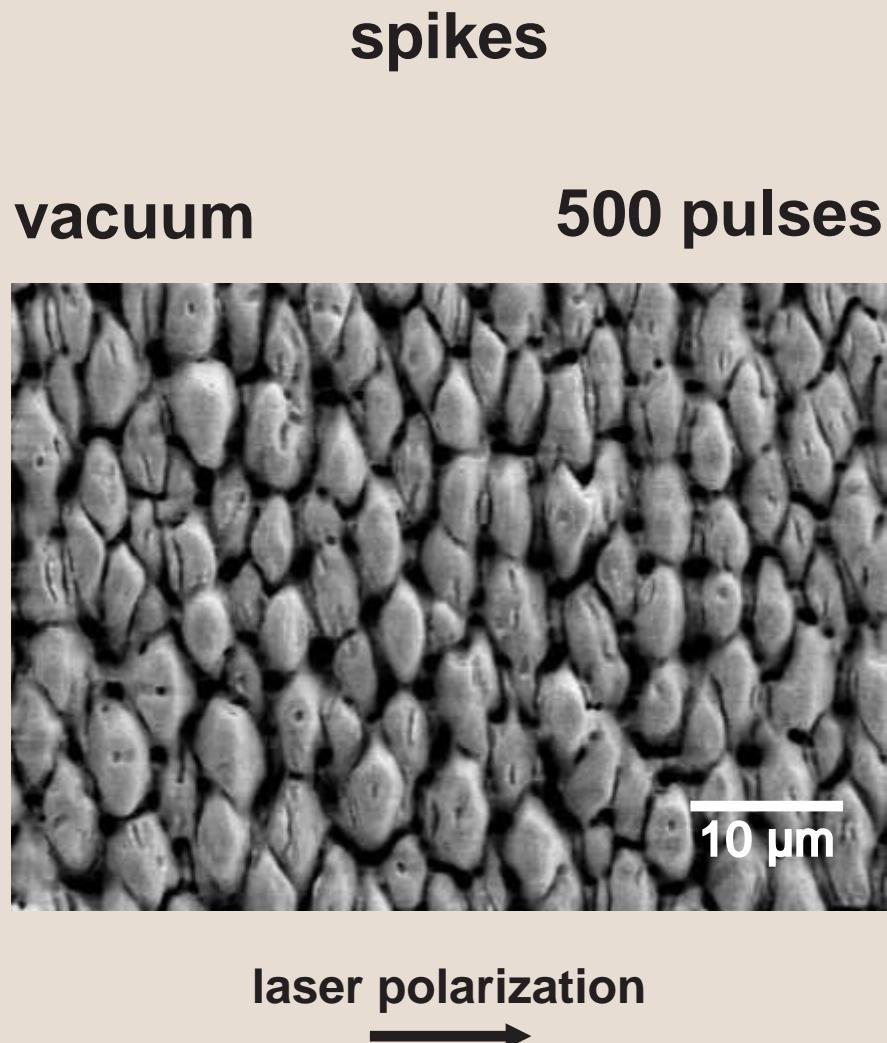
laser polarization
→



Microspike development



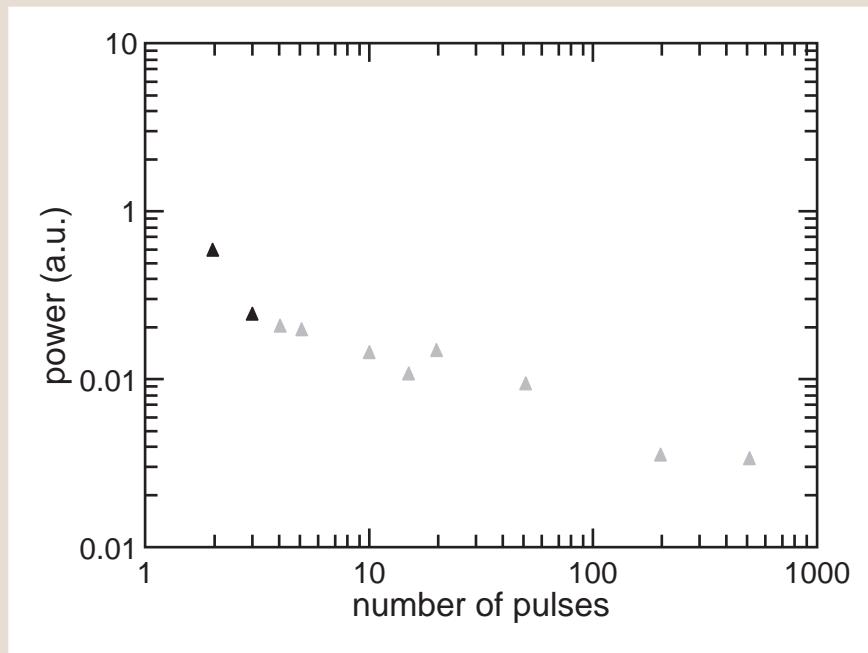
Microspike development



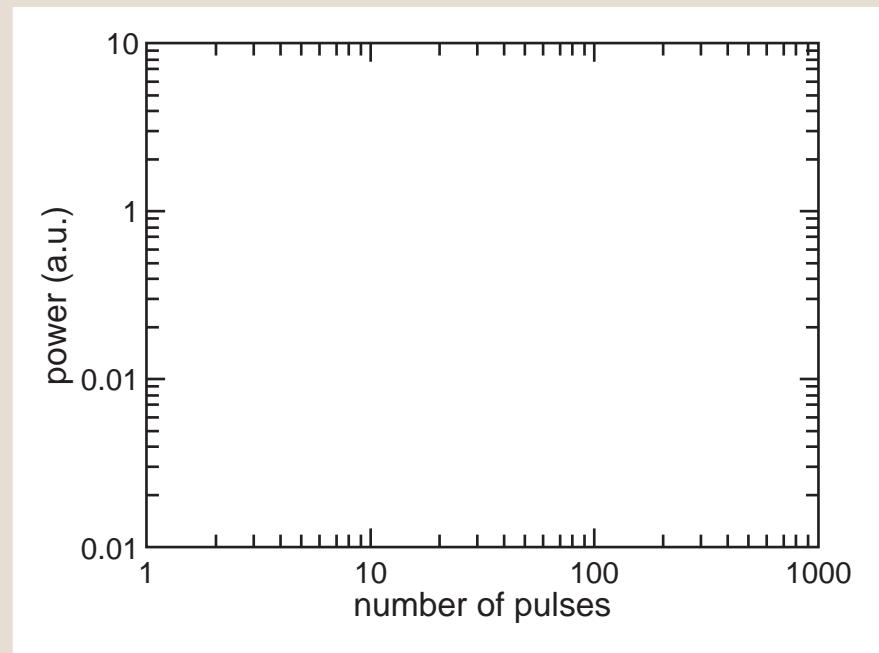
Microspike development

peak intensities

SF₆ ripples



parallel

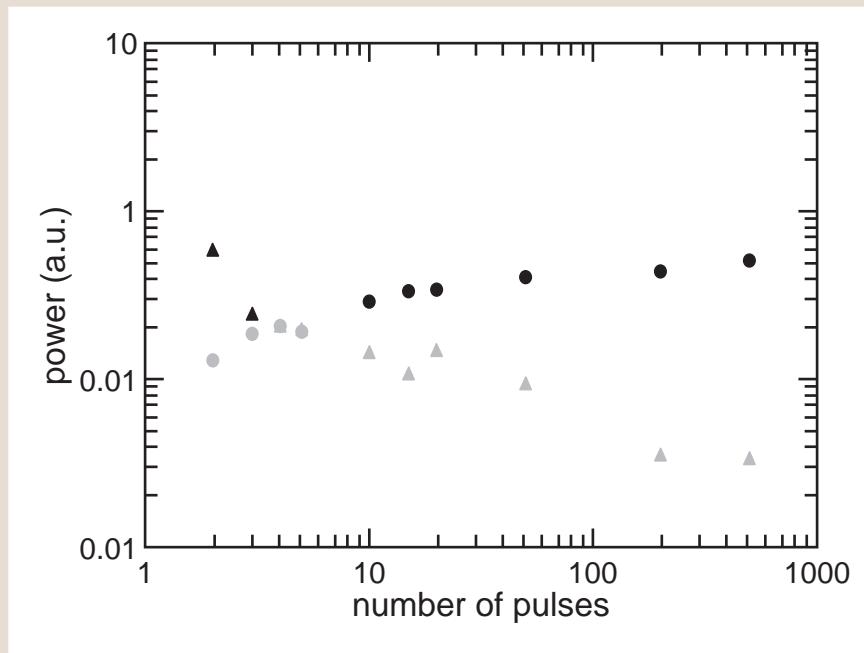


perpendicular

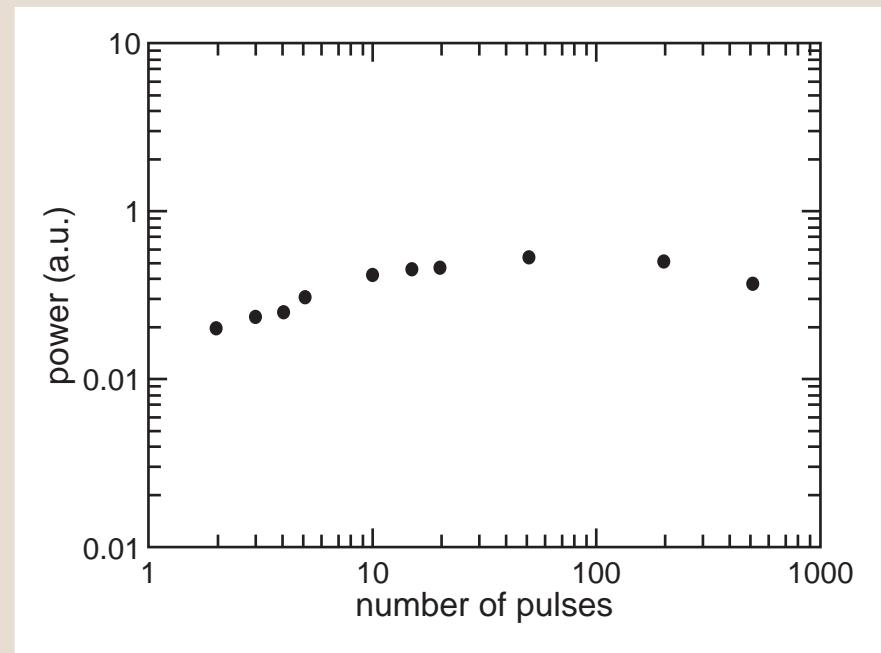
Microspike development

peak intensities

SF₆ spikes



parallel

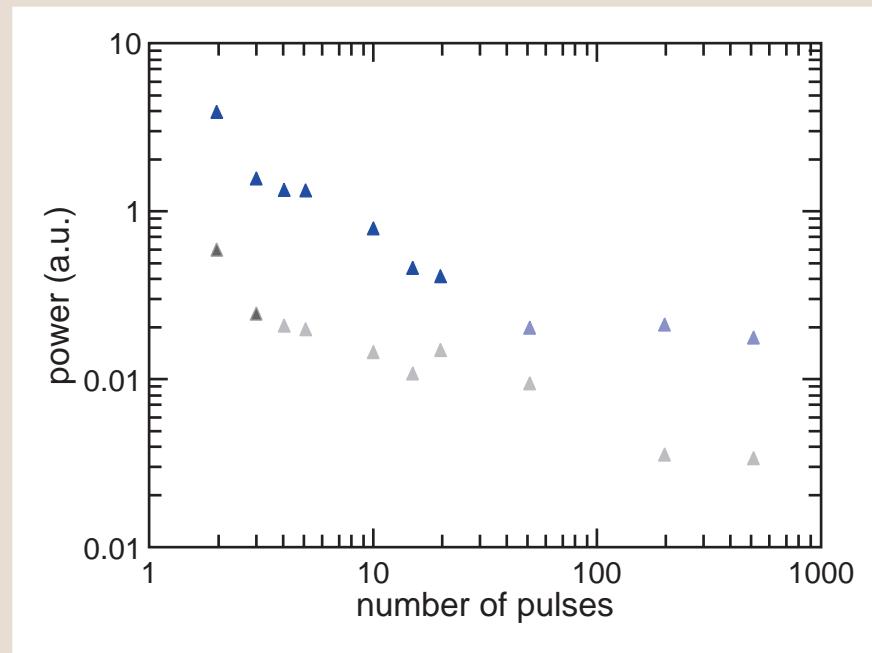


perpendicular

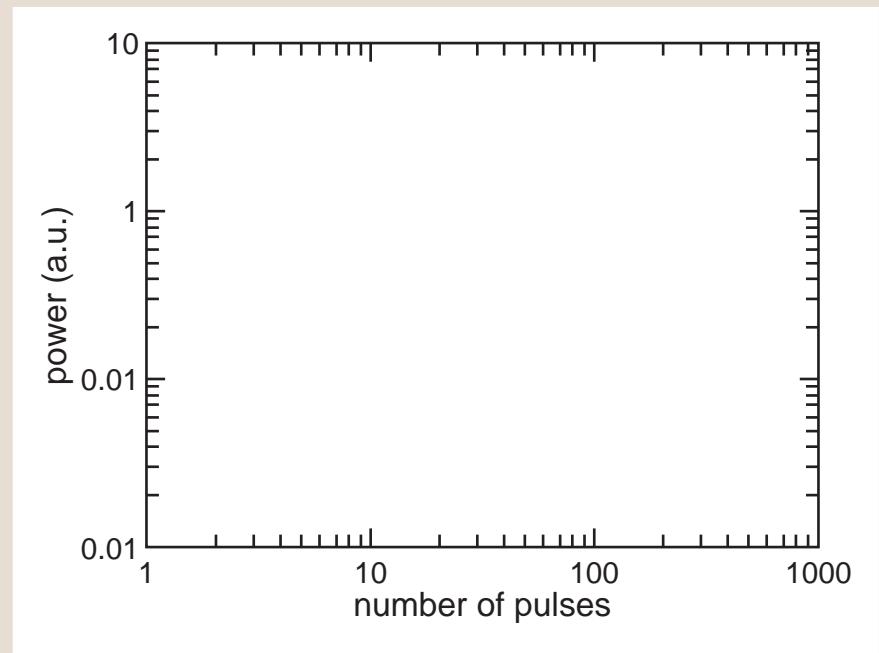
Microspike development

peak intensities

vacuum ripples



parallel

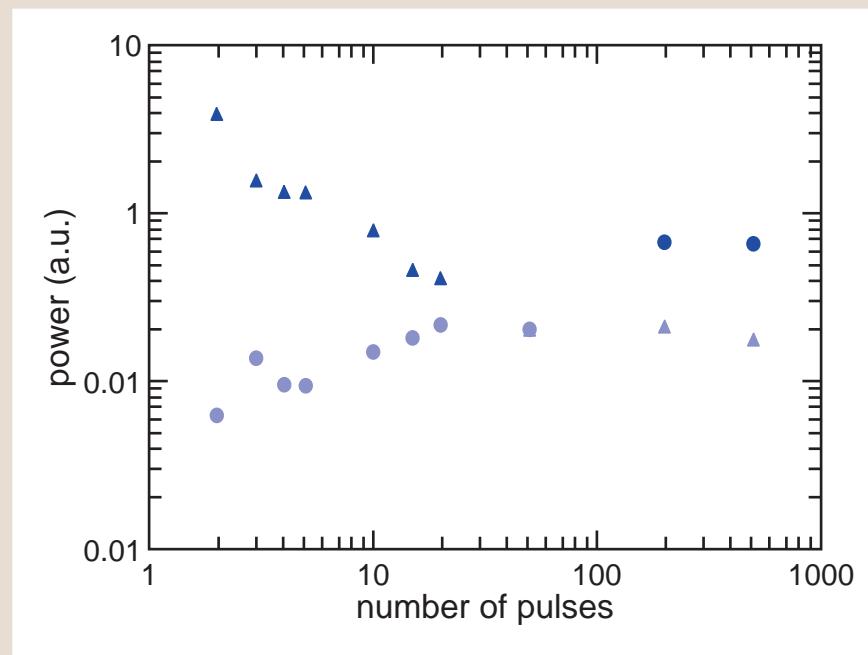


perpendicular

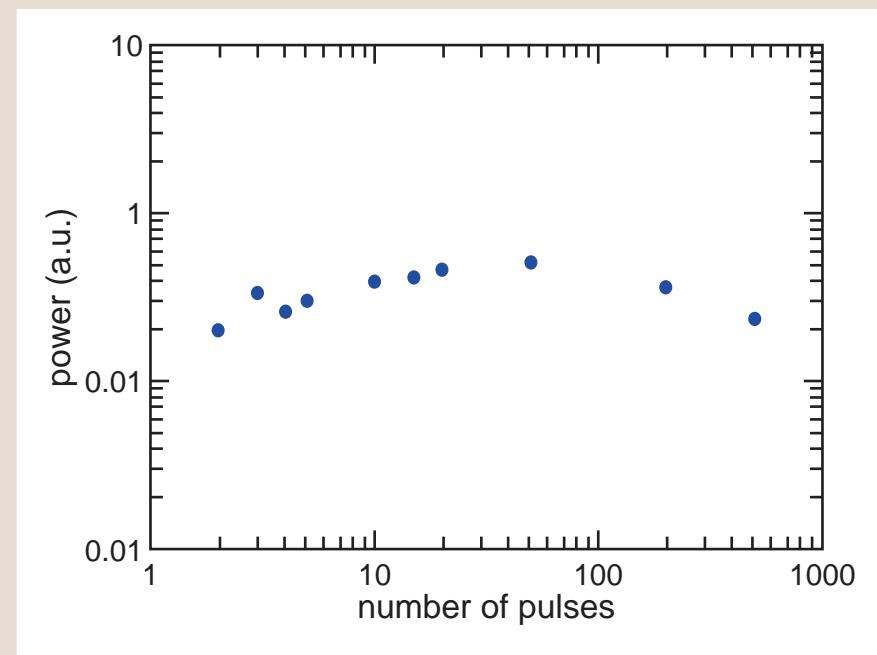
Microspike development

peak intensities

vacuum spikes



parallel

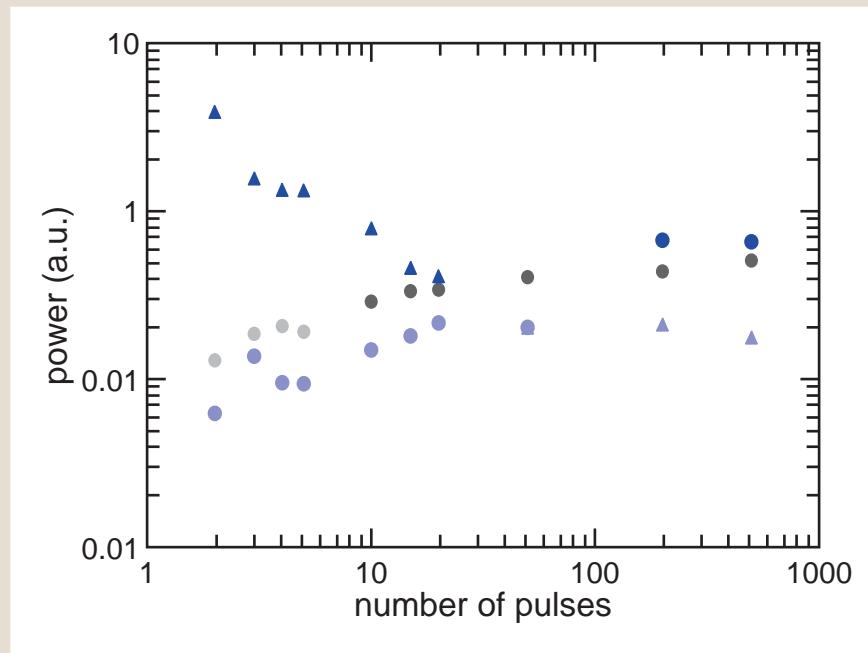


perpendicular

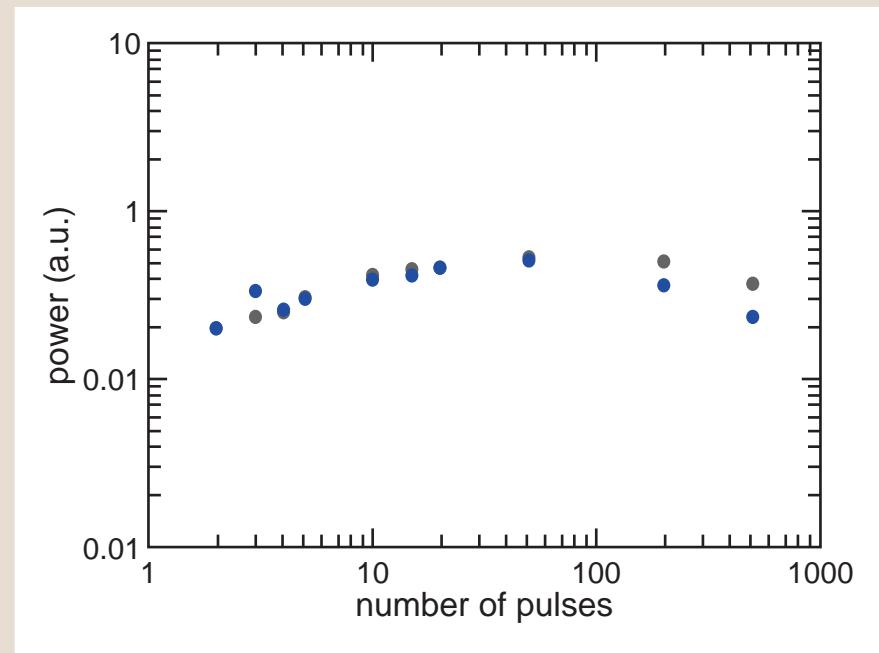
Microspike development

peak intensities

vacuum spikes

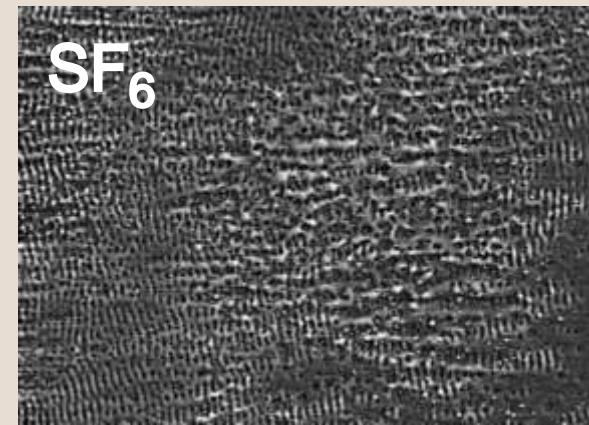


parallel

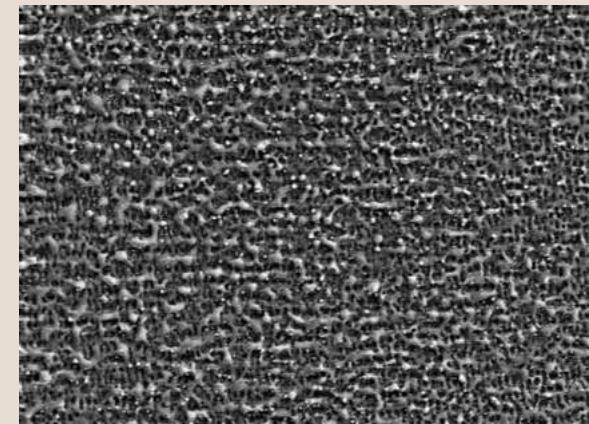


perpendicular

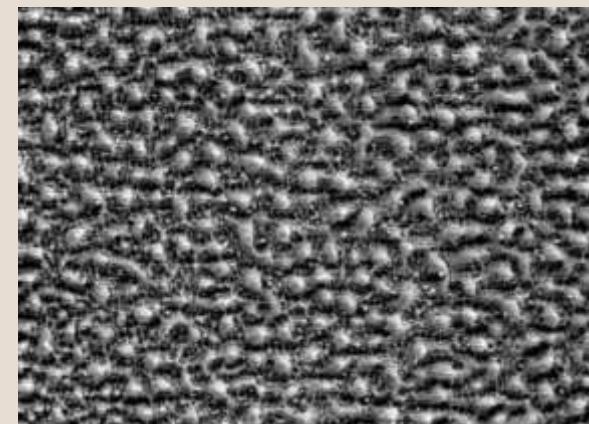
**1. Interference ripples
(\perp to polarization)**



**2. Coarsened ridges
(\perp to ripples)**



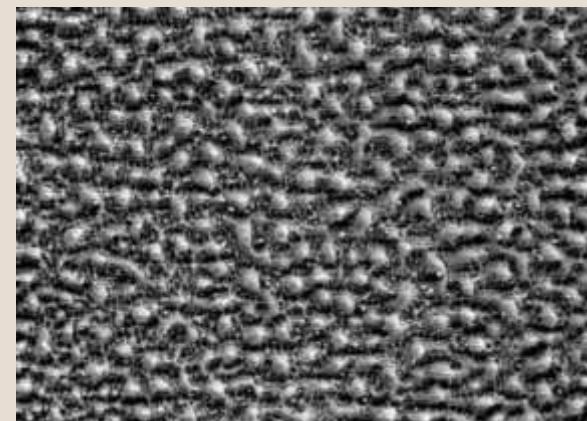
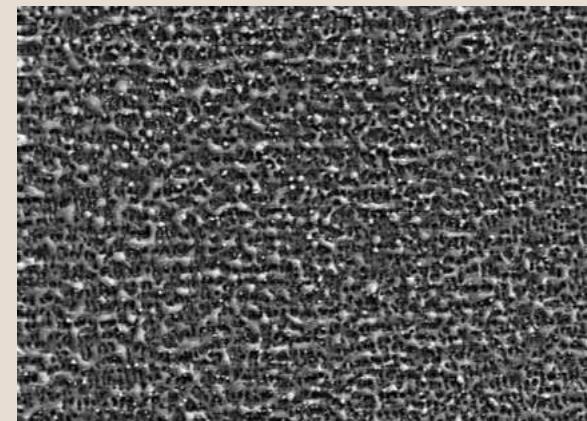
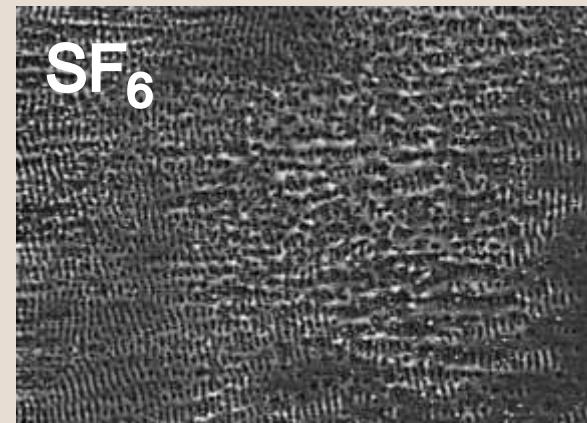
**3. Beads sharpening
into spikes**



Length scales:

spike wavelength appears as
ripple wavelength disappears

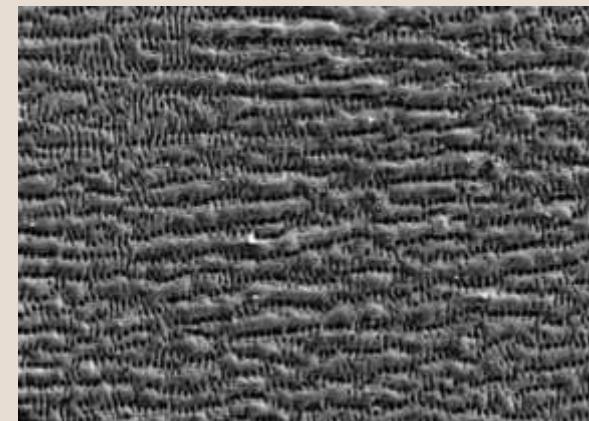
spike wavelength first appears
perpendicular to polarization



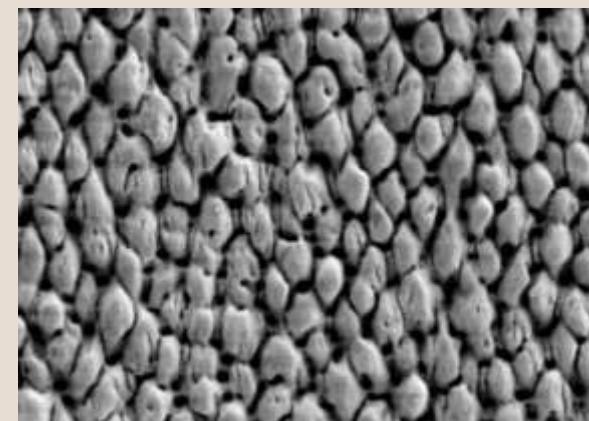
**1. Interference ripples
(\perp to polarization)**



**2. Coarsened ridges
(\perp to ripples)**



**3. Beads sharpening
into spikes**



SF₆ vs. vacuum:

spatial frequencies very similar

development progresses faster in SF₆

ridges extend farther in vacuum

vacuum spikes are more blunt

What sets the length scales?

ripples: laser wavelength

ridges and spikes: perhaps capillary waves

Why are SF₆ and vacuum different?

SF₆ etches surface efficiently

fluid dynamics affected by pressure, impurities

These results: evolution of length scales

Next steps: fluid dynamics

Much more to explore!

Acknowledgements

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**Discussions: Howard Stone, Jacqueline
Ashmore, Adela Ben-Yakar, Michael Brenner**

**For a copy of this talk and
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