High intensity microparticle propulsion with light – and more

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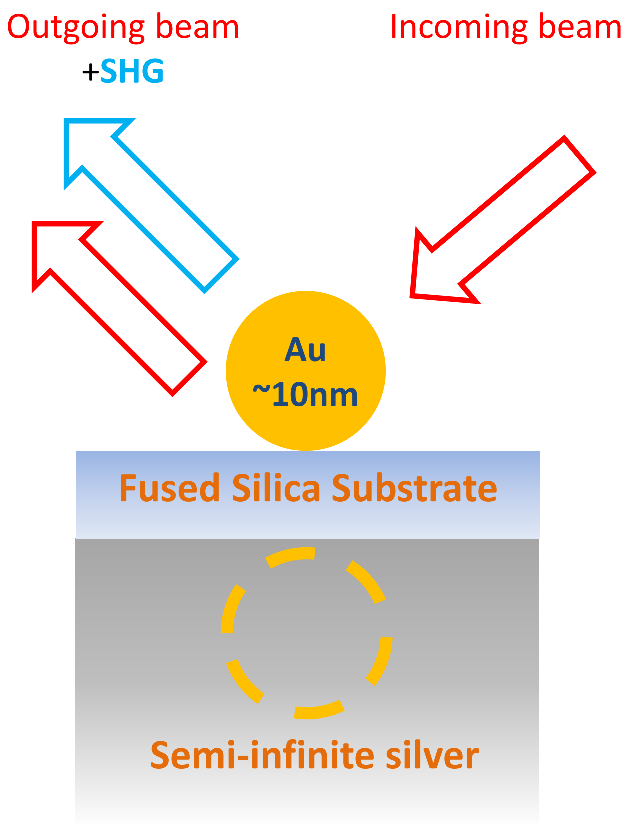
Research at the optics lab of the solar cell center

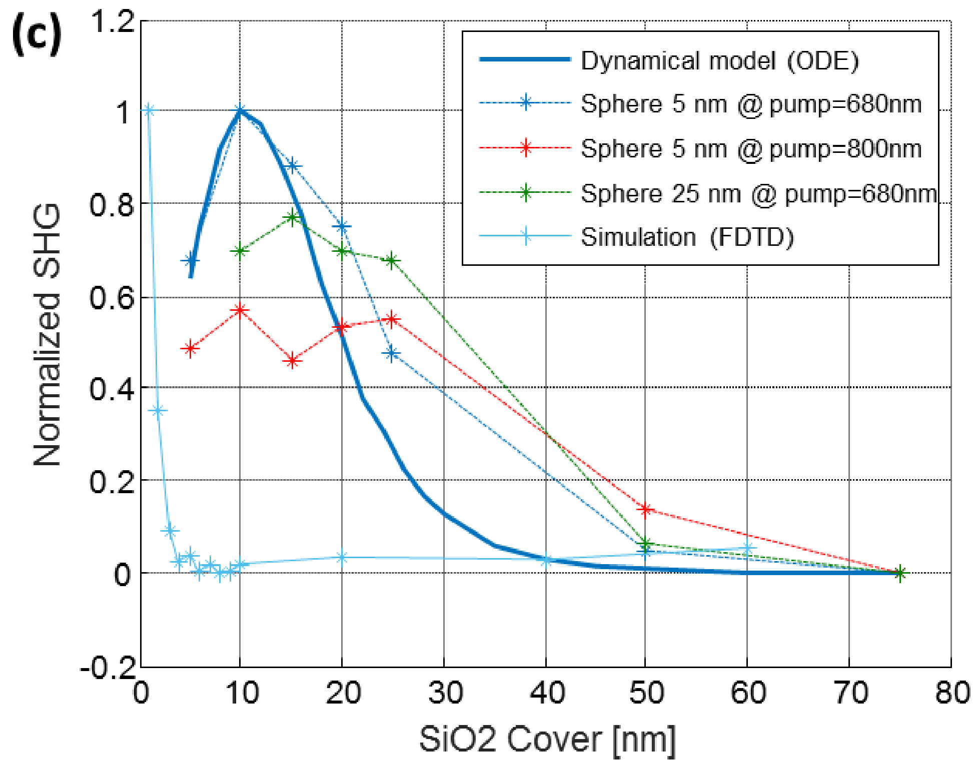
- **Nonlinear optics of metals at the extrema nanoscale**
- **Light generated propulsion of micro-particles**
- **Advanced optics for solar cells**

Group Website:

http://avinivkb.wix.com/lmi-sb

Nonlinear optics of metals at the extrema nanoscale



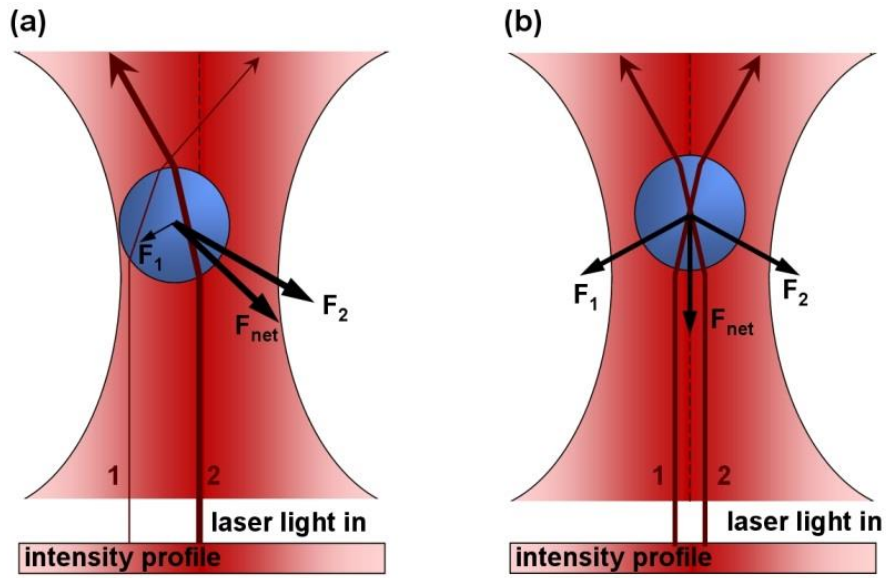


Evidence of yet unknown kind of light-matter interaction!

Light generated propulsion of micro-particles - Motivation

- Drug delivery, diagnostics, and other in-vivo therapeutic procedures
- Biology, physics in the micro and nanoscale, surface science
- Bottom-up fabrication procedures
- Micro-machines and microfluidic devices
- **Advanced optics of solar cells**

Existing approaches – Optical tweezers



- Optical tweezers are based on *momentum transfer* between the electromagnetic wave and the solid object they interact with
- For practical reasons the forces from optical tweezers is in the pico-Newton range (10^{-12} N).

What if much larger forces are needed?

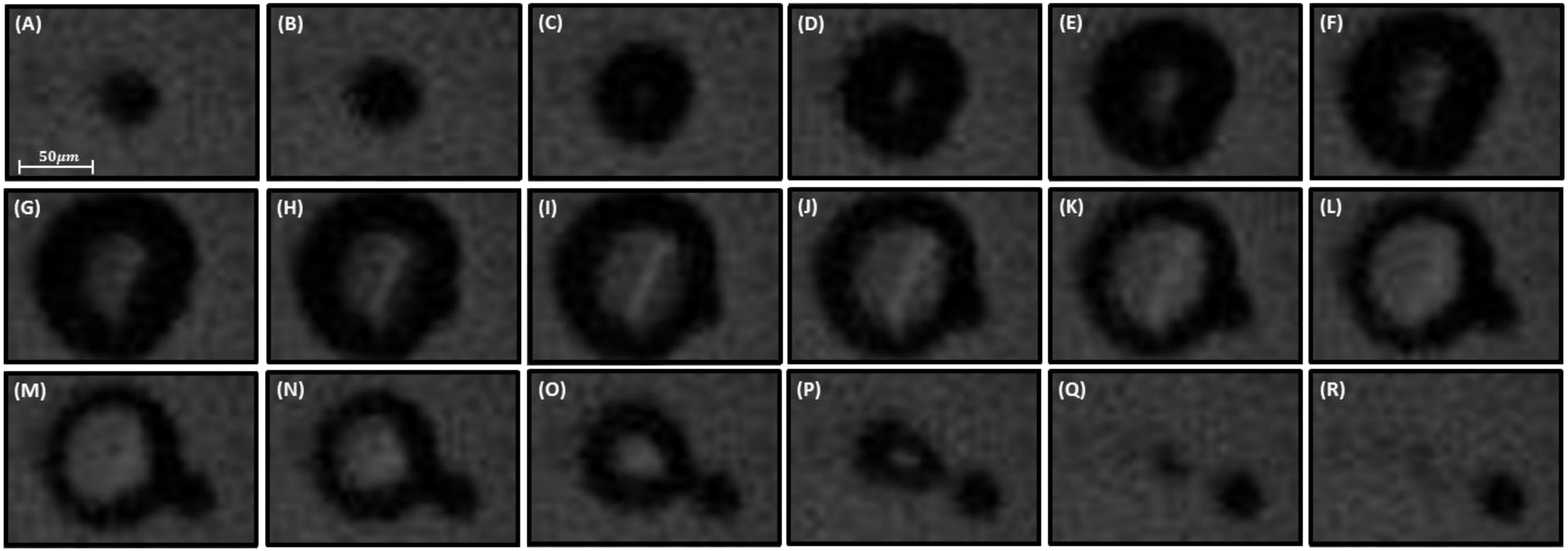
- We propose the energy of light for inflecting motion (rather then its momentum)
- We demonstrate force of μN (10^{-6} N) - *million times more than what is common*
- Source: light-generated heat + phase transition in water

Real-time view of the process

High frame rate (500,000 FPS) view of the process

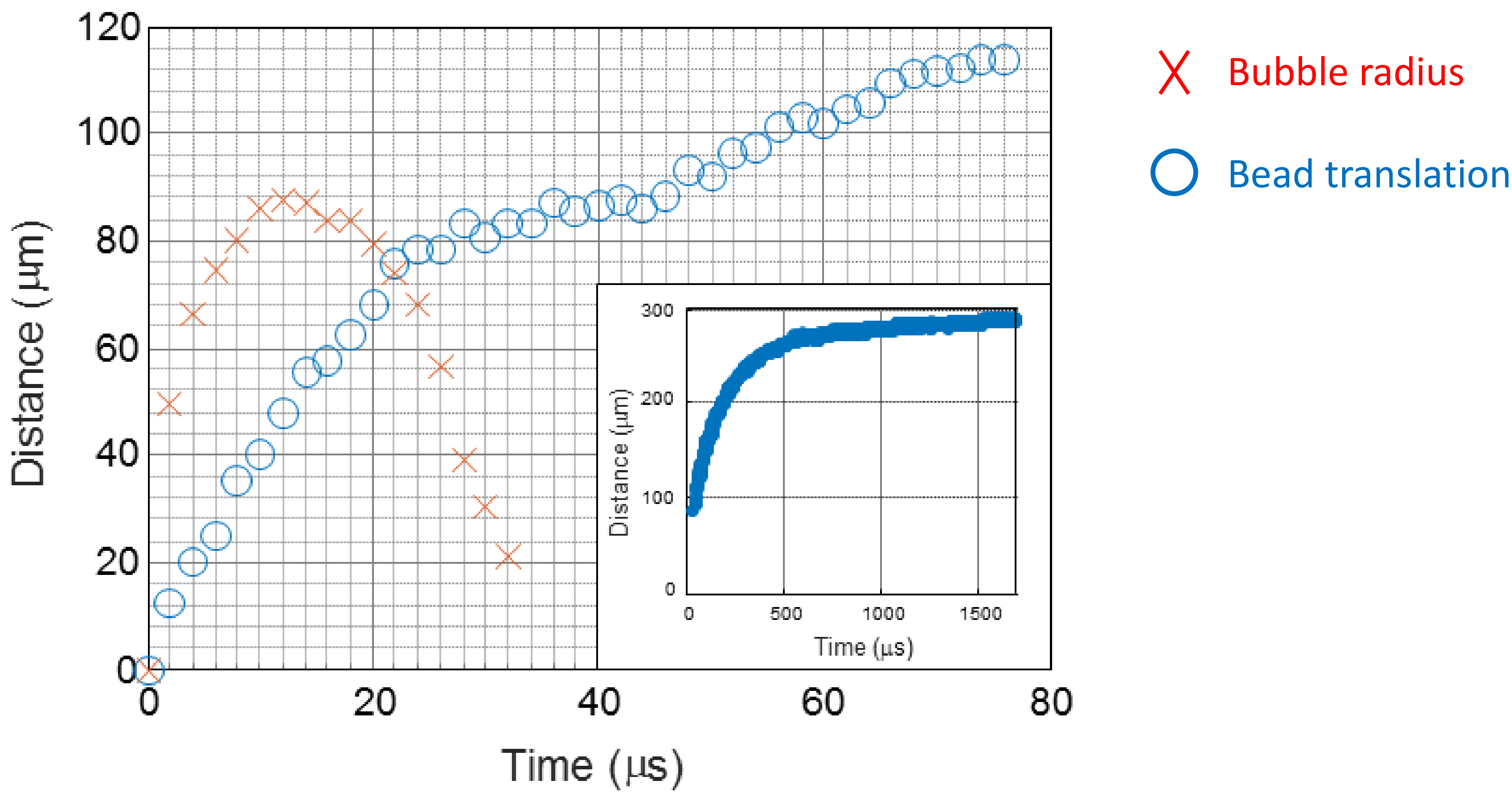
Camera at the courtesy of Prof. Oren Sadot, ME dept. BGU

High frame-rate capture

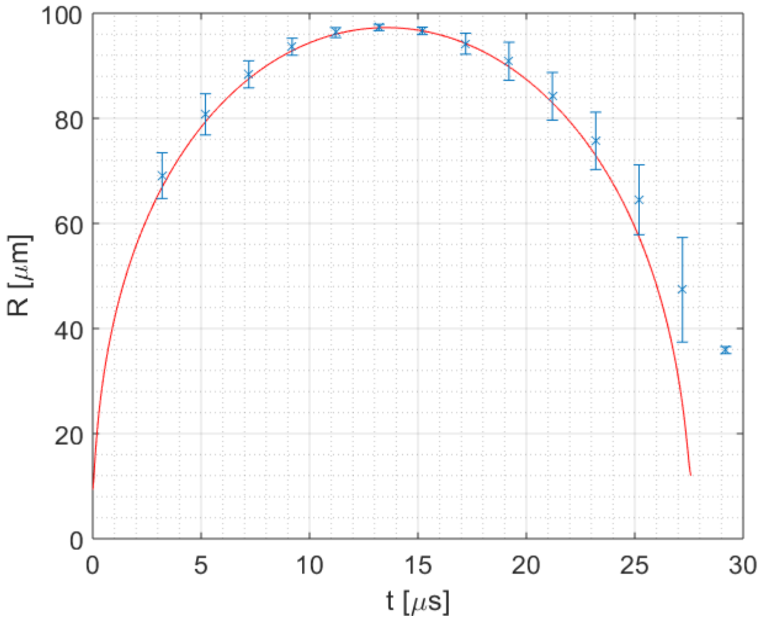


- Figures are captured at 500,000 frames per second (2 μs between consecutive images)
- Phantom v12 camera at the curtesy of Professor Oren Sadot (ME BGU)

Bead motion and bubble radius



Average motion of the most probable occurrences



Red line – Prediction form the Rayleigh-Plesset equation

$$P_V(t) - P_\infty - P_S = \rho\left[R(t)\ddot{R}(t) + \frac{3}{2}\dot{R}(t)\right]$$

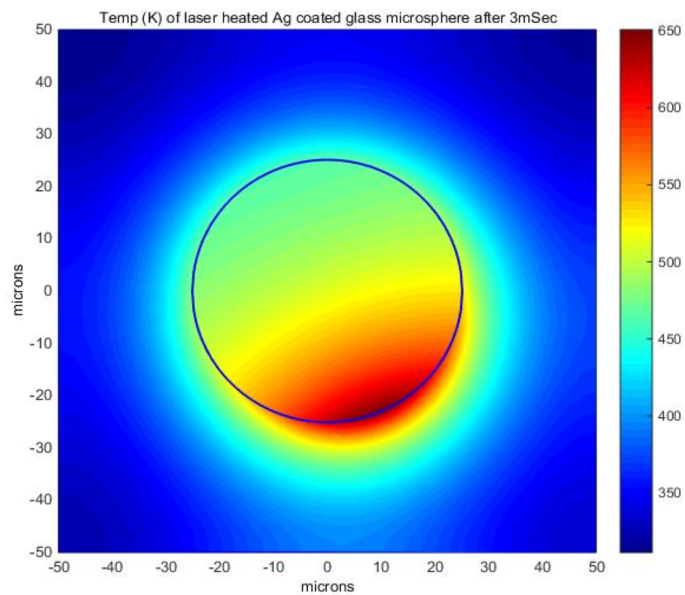
$$P_V(t) = P_0\left(\frac{R_0}{R(t)}\right)^{3\gamma}$$

$$P_S(t) = \frac{2S}{R(t)}$$

Considering average bubble radius allows good comparison with known models

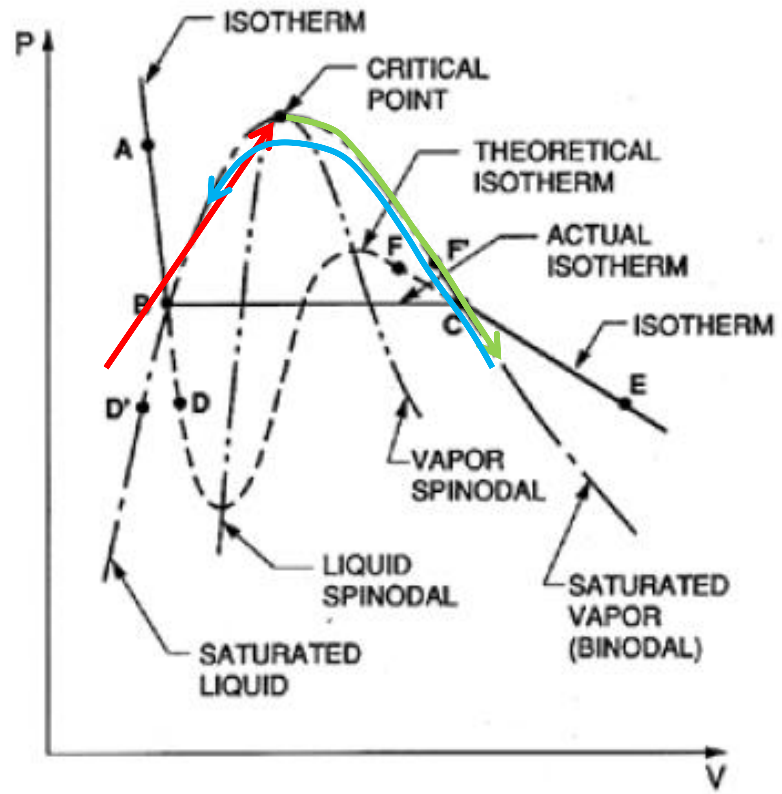
Heat convection prior to phase transition

- Temperature after $3\ ms$ of heating with $100\ mW$ Gaussian beam with $10\ \mu m$ waist focused at the lower right side of a $40\ \mu m$ silver coated glass bead
- The simulation shows that the water reached $600\ K$, close to the saturation temperature of water

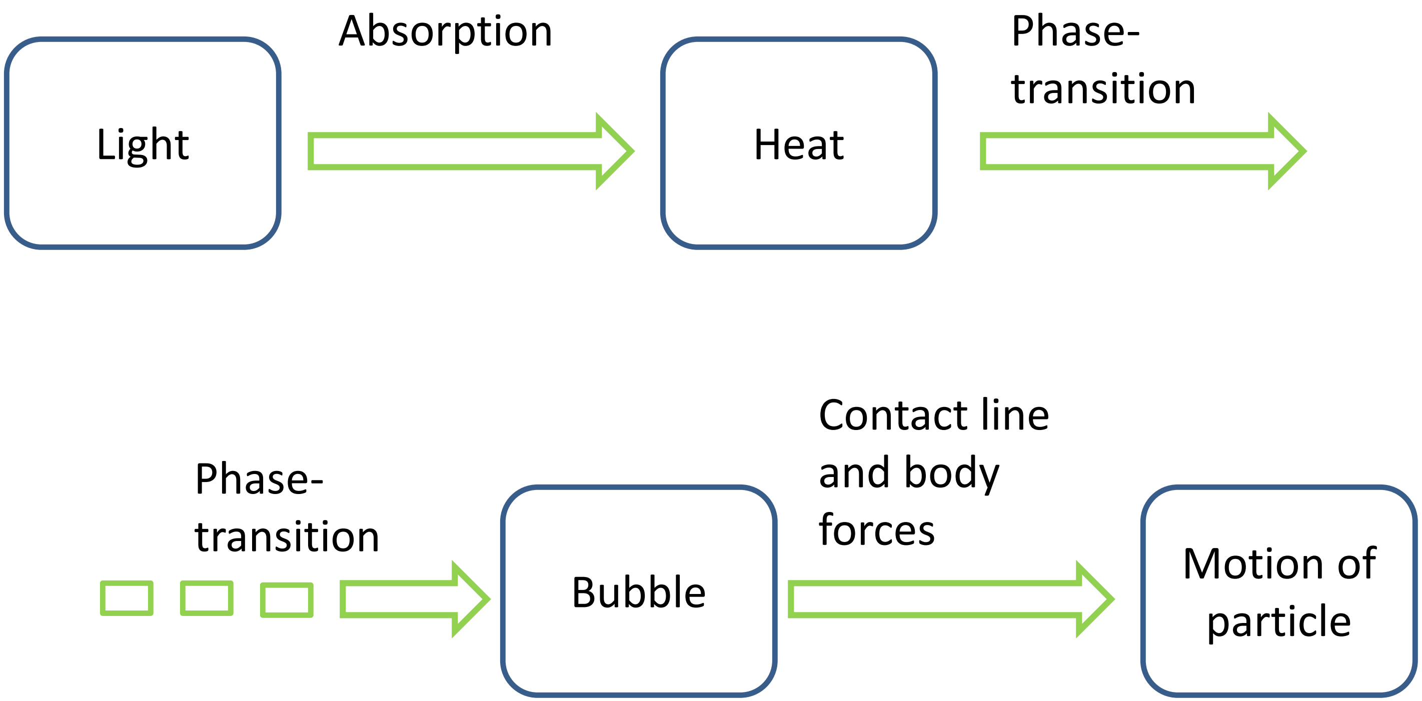


The process on the P-V diagram

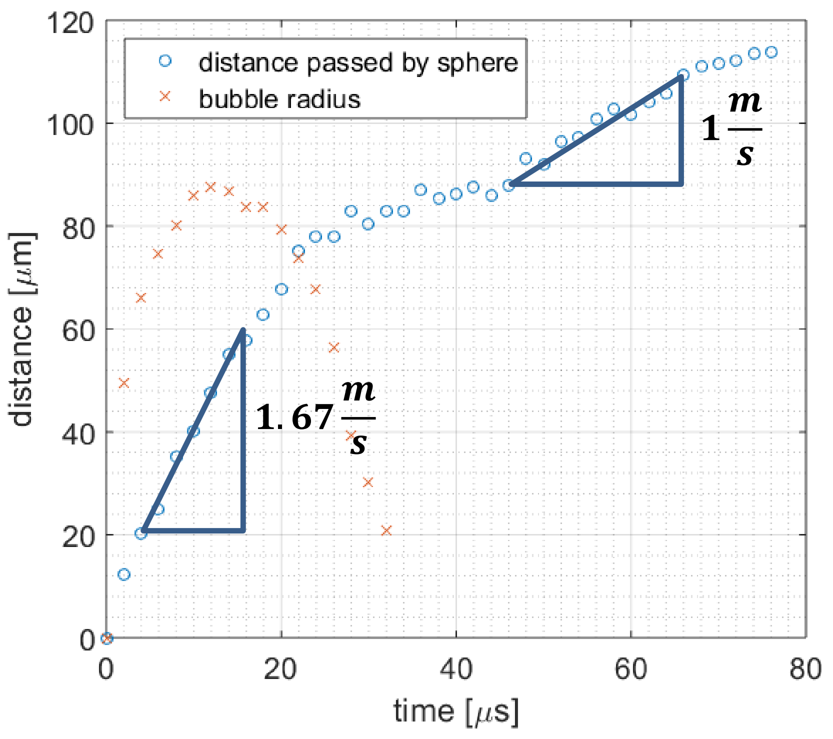
- Heating (few msec) of saturated liquid, ending with a phase transition (less then μsec)
- Adiabatic expansion (tens of μsec)
- Almost adiabatic contraction (tens of μsec)
- The area between the green and the blue lines denotes non-adiabatic process such as: friction, emission of shockwave, and dissipation of heat



Chain of events



Let us estimate the velocity and the force again



$\Delta t = 40\ \mu s$; $v = 1\ m/s$; and $M = 8.4 \times 10^{-11}\ kg$:

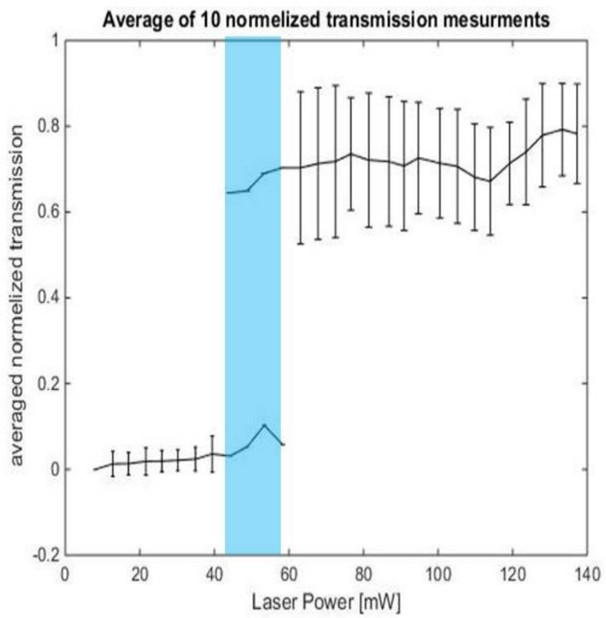
$$F = \frac{Mv}{\Delta t} \approx 2\ \mu N$$

That is six order of magnitude larger then what was observed so far

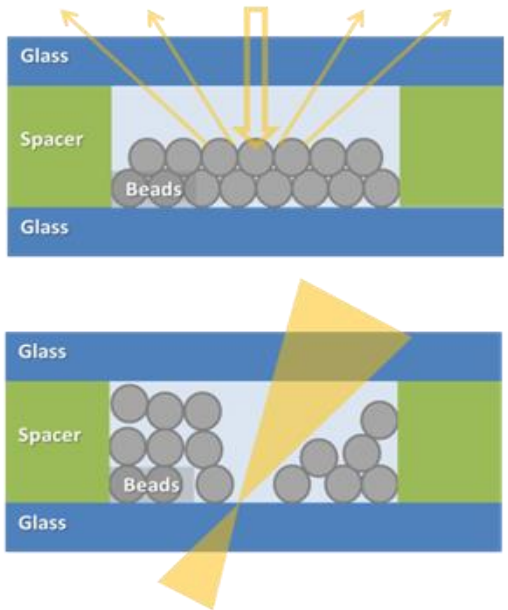
Reorganization of a dens collection of beads

Experimental Results

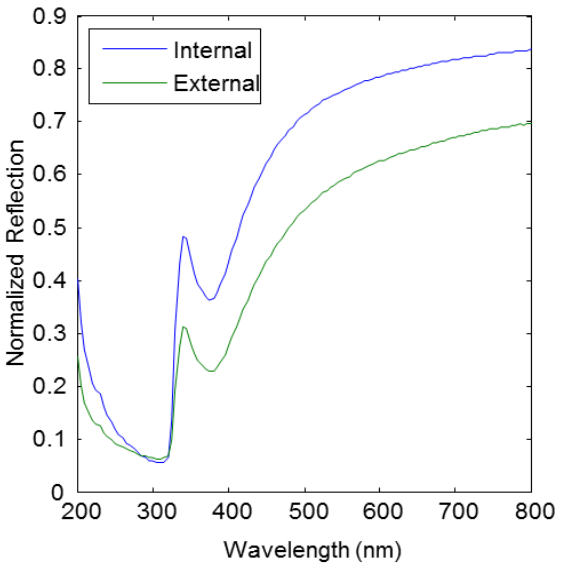
Transmission



Schematics of sample



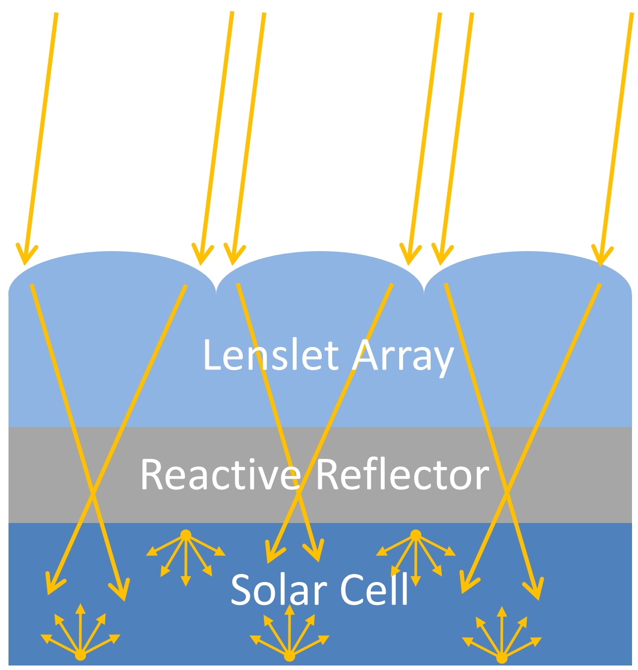
Reflection

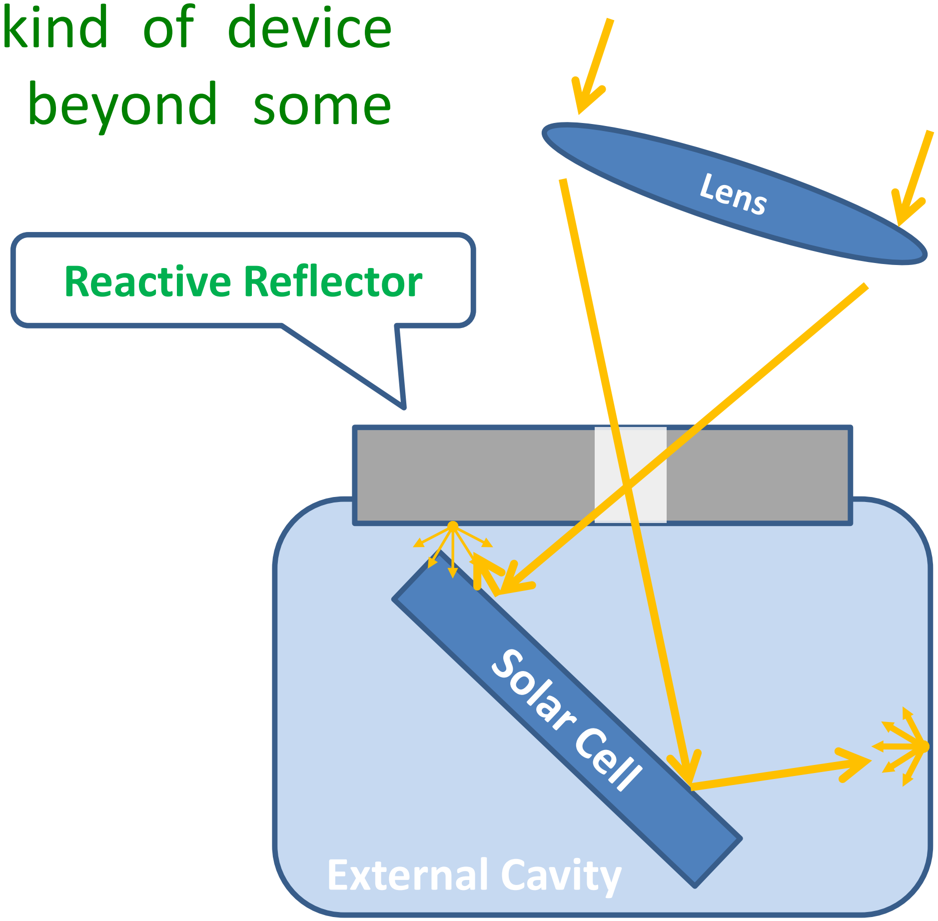


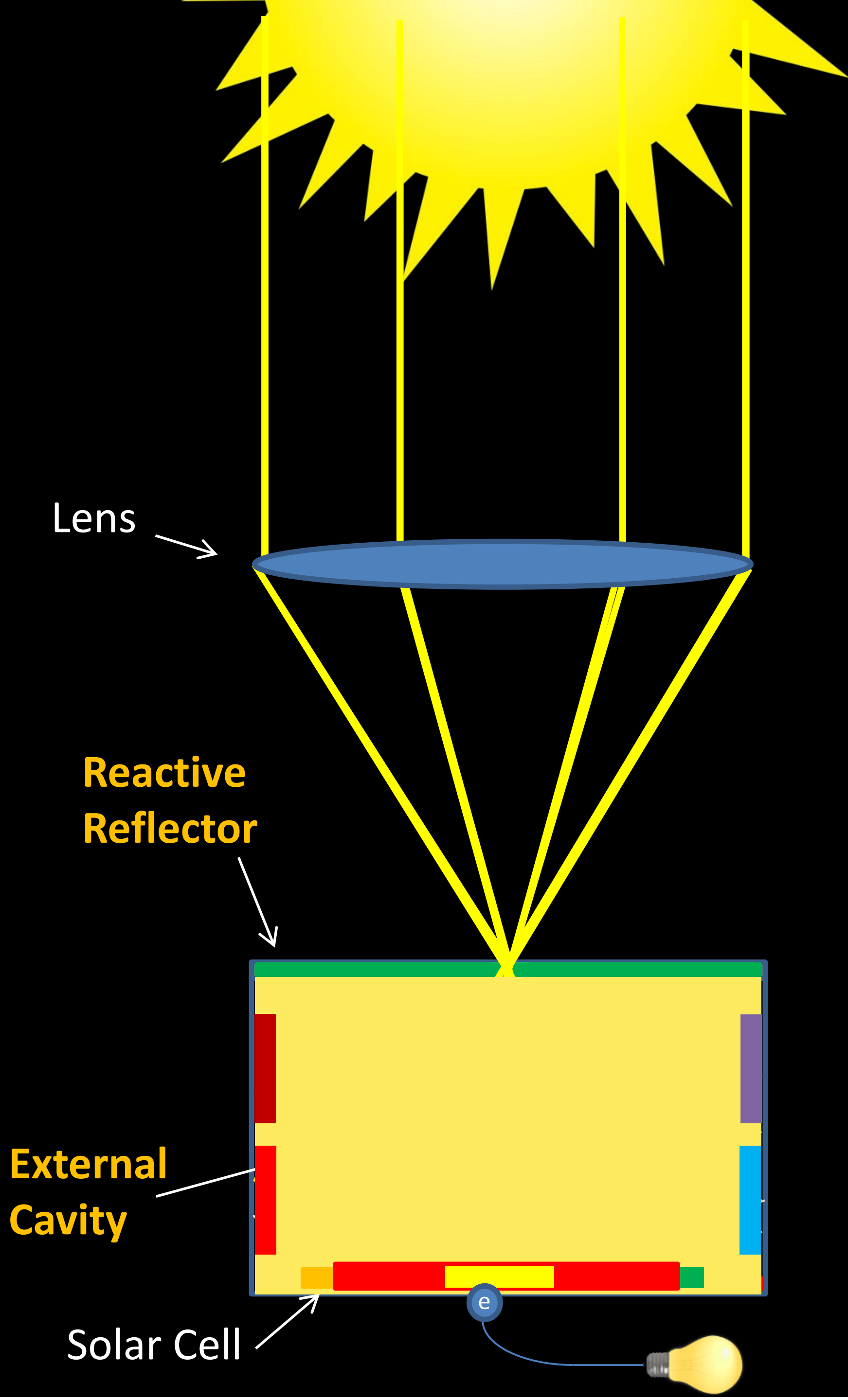
Advanced optics for solar cells:

Passive Tracking + External Cavity

A Reactive Reflector is a kind of device that becomes transparent beyond some intensity threshold.







Passive tracking + External cavities:

- Maintains power using smaller modules
- More power per module as of diffused illumination
- Lower recombinations with thinner cells
- Achieve ultra-high efficiency with spectral splitting
- Introducing new materials into the solar industry

This is equivalent to concentrated solar without the cost of active tracking

Acknowledgments

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Students:

Ido Frenkel (PhD)

Shlomi Levi (MsC)

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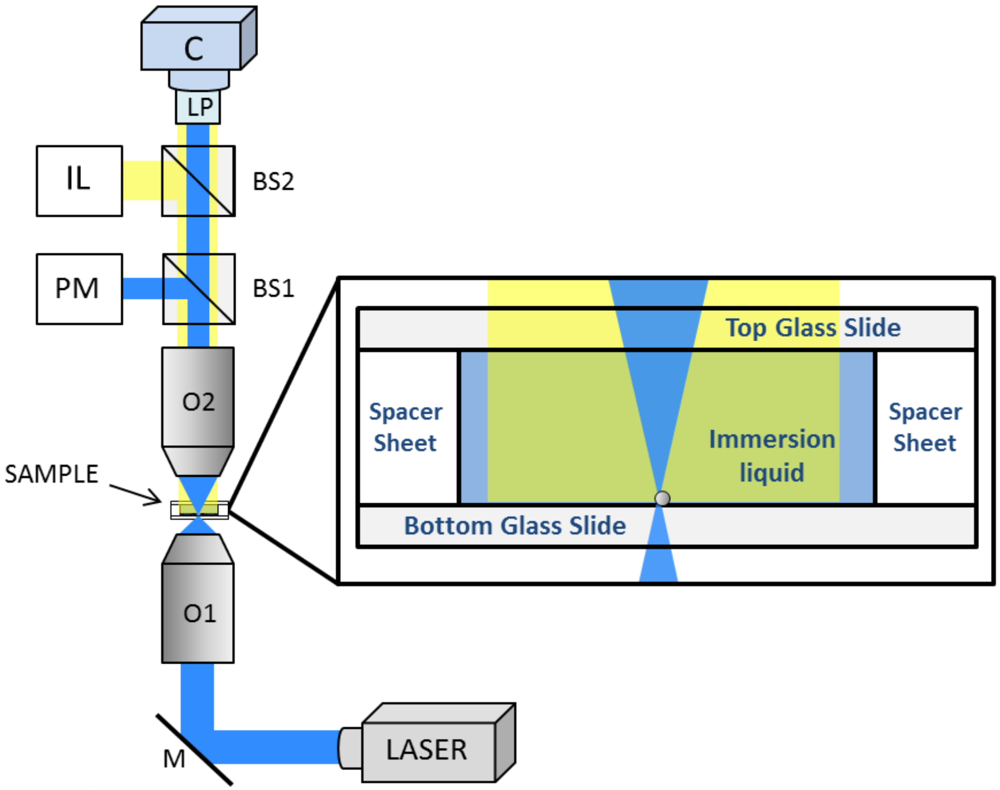
The experimental setup



Simulation parameters

$$P_V(t) - P_\infty - P_S = \rho\left[R(t)\ddot{R}(t) + \frac{3}{2}\dot{R}(t)\right]$$

$$P_V(t) = P_0\left(\frac{R_0}{R(t)}\right)^{3\gamma}$$

$$P_S(t) = \frac{2S}{R(t)}$$

$P_0 = 22.064\ MPa$ (pressure at the critical point for water)

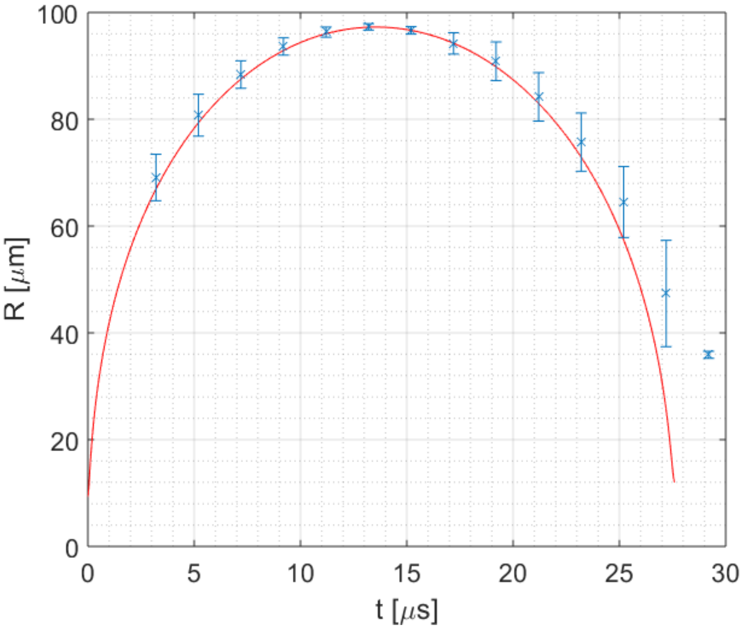
$P_\infty = 40\ kPa$ (100 kPa atmospheric pressure)

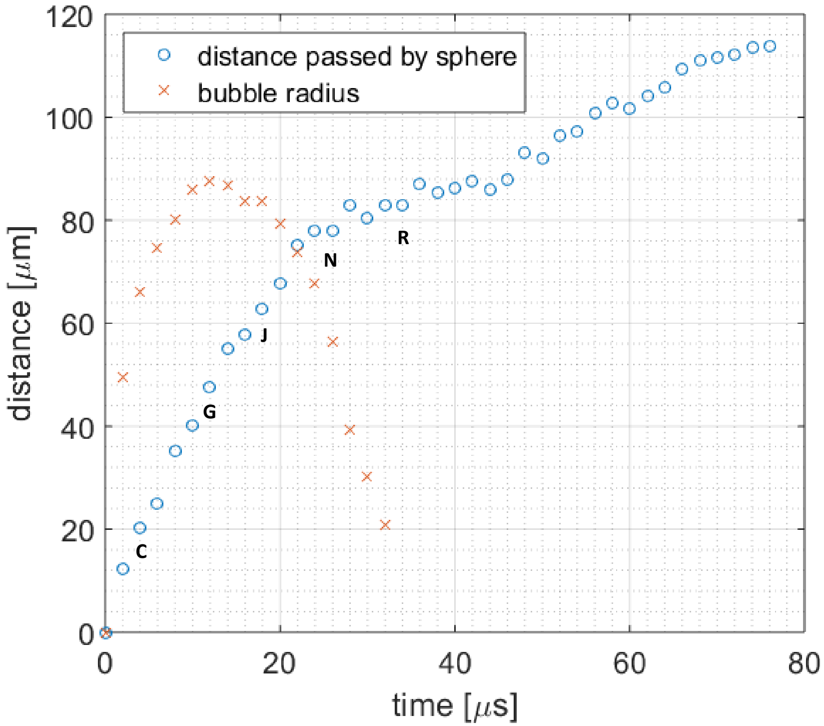
$R_0 = 7\ \mu\text{m}$

$\gamma = 1.33$ (= C_p/C_v)

$\rho = 1000\ \ kg/m^3$

$S = 0.07\ \ N/m$





Bead

- Acceleration up to *C*
- Constant velocity up to *L*
- Slowing down at N
- Lower speed at R
- Acceleration at $40\ \mu s$, which is $\sim 10\ \mu s$ after bubble vanishes , may indicate emission of shock-waves

Bubble

- Expansion up to *G*
- Collapse up to *R*
- Vanishes completely afterwards