# Eminence of Slip Length Due to the Emergence of Viscoelastic Flow at the Nanoscale

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## Motivation

Over the past several decades excitement has grown over using nanoparticles (NP) as devices which maximize their unique optical and mechanical properties. Ultrasensitive mass sensors have been realized using nanostructures to provide atomic-scale mass resolution. Relying on the known mechanical vibrations of these devices, shifts in frequency are detected once a molecule adsorbs to the surface increasing the overall mass of the device. For sensing within a liquid environment, damping of the resonating device, by the liquid, can mask the vibrations completely - resulting in an over-damped response. Thus, a complete understanding of the dynamical response of vibrating nanostructures is vital.

## Background

**Optics Background**

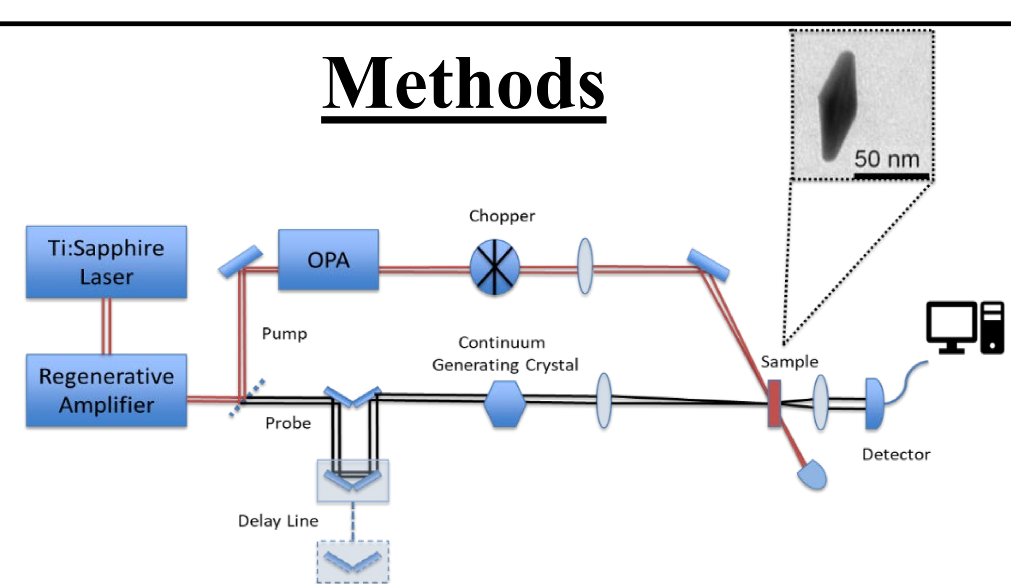
- Plasmon: collective oscillation of conduction electrons
- Plasmon frequency dependent on size and shape of the metal nanoparticle

**Fluid Mechanics Background**

- Simple liquids - single phase/short molecular lengths - typically described by a viscous Newtonian response
- Viscoelastic liquids – multiphase/long molecular lengths – have complex response with both viscous damping and energy storage

- No-slip boundary condition: Velocity of the fluid relative to the object is zero
- Slip length: length from the object's surface to the point with zero velocity
- No-slip B.C. doesn't hold for gases, but is typically applied in conventional fluid mechanics

## Methods




- Transient absorption measurements performed using pump-probe technique Laser pulses are ~120fs
- Pump pulse tuned to the plasmon resonance of the NP to excite the sample
- Probe pulse directed along a delay line to change when it arrives at the sample
- The transmission is collected and directed to a spectrometer to determine the change in absorption at a given pump-probe delay time

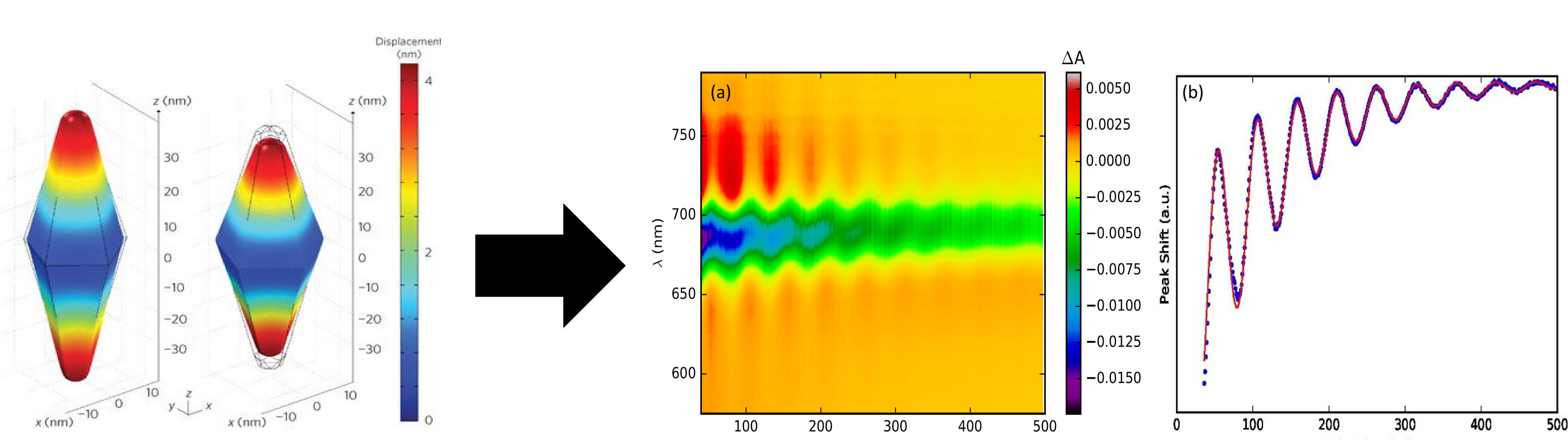



Image adapted from Ref. 1

- Absorption of the laser pulse causes the NP to rapidly expand
- Mechanical oscillations - expansion and contraction of the NP geometry - are excited which causes corresponding shifts in the plasmon resonance
- This is monitored through changes in absorption at wavelengths around the plasmon resonance
- Energy is dissipated to the surrounding liquid from these oscillations
- Dissipation rate is dependent on the properties of the liquid

## Results & Conclusions

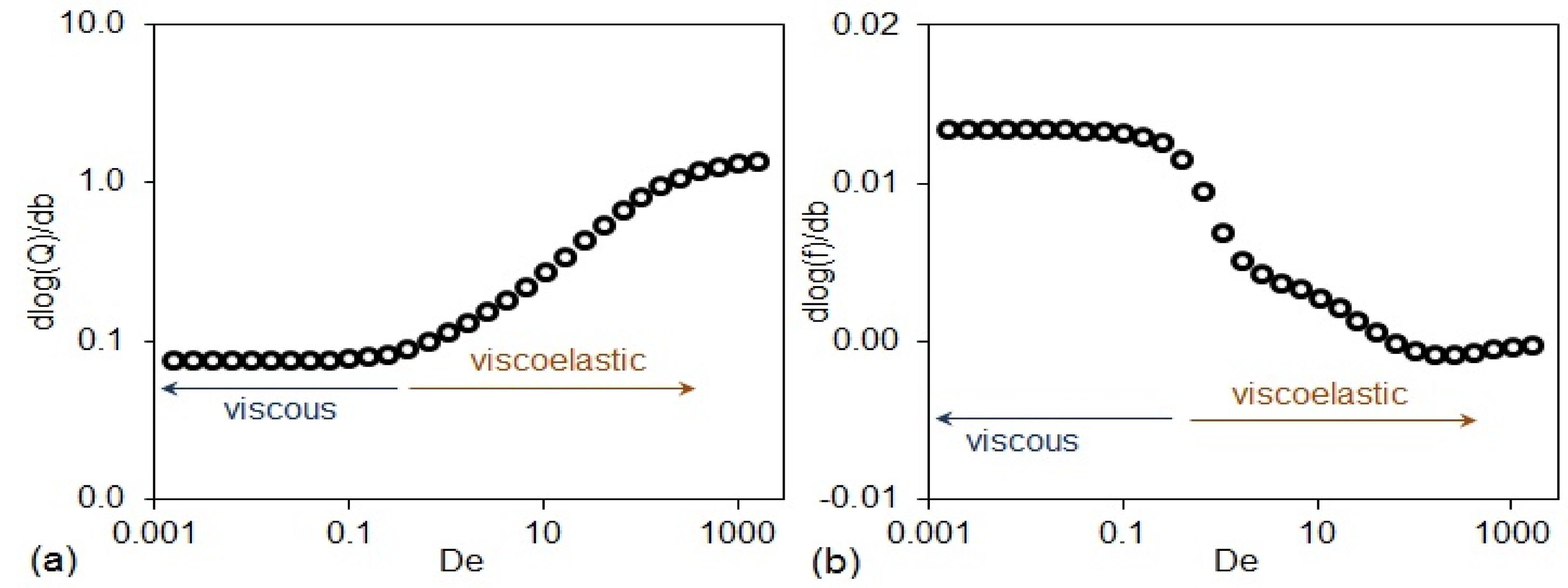
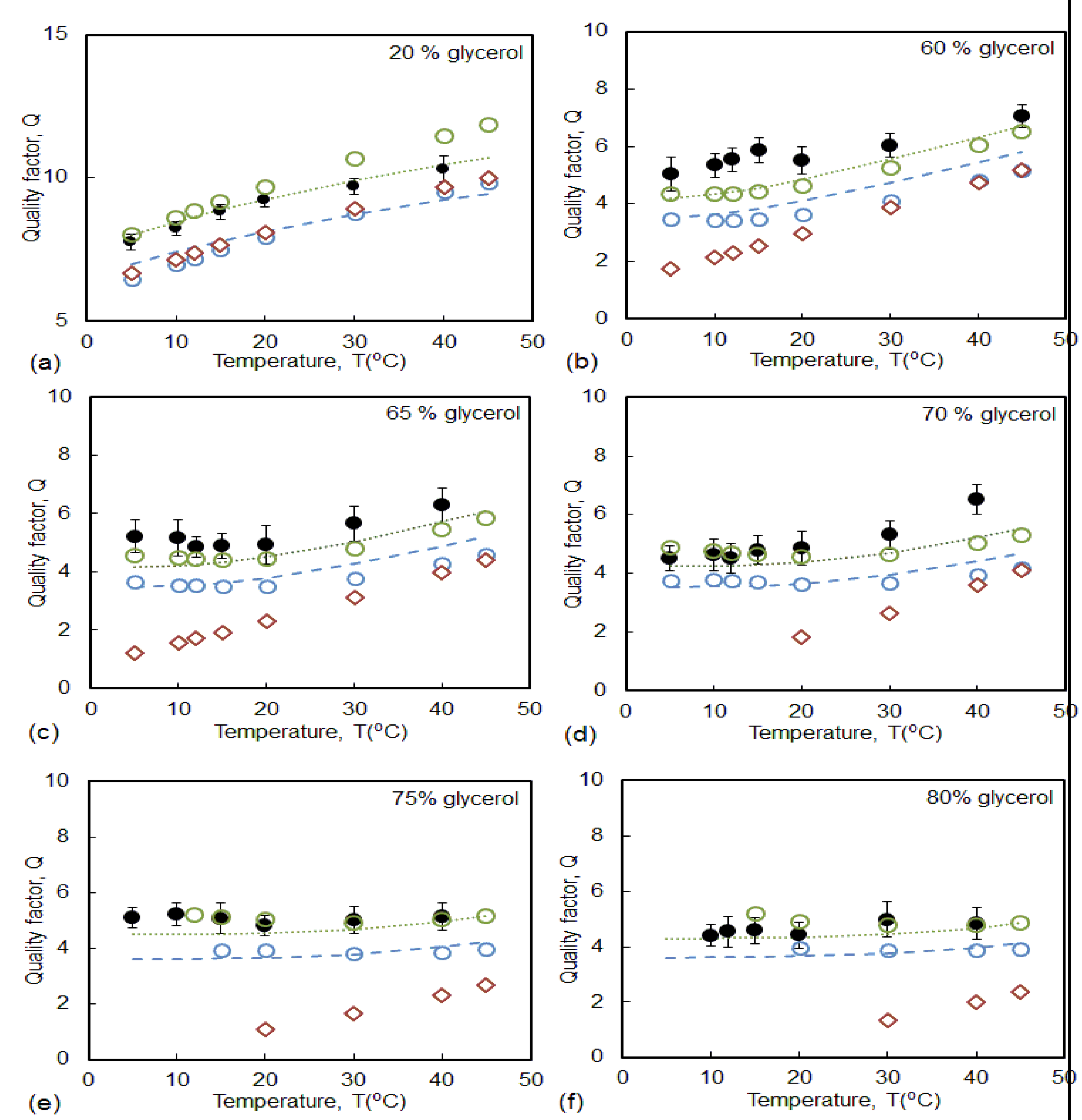



Image courtesy of D. Chakraborty

Theoretical predictions of the influence of slip length on (a) quality factor and (b) frequency, as a function of Deborah number. The derivatives are taken with respect to slip length.

**Effects of slip flow are enhanced with the transition from Newtonian to viscoelastic flow in the liquid.**




Quality factors for nanoparticle vibrations in viscoelastic fluid with no-slip and slip solid-liquid interface, as a function of temperature and concentration on glycerol.

- ● Experiment
- ● Finite-Element viscoelastic with Slip length 2nm
- ● Finite-Element viscoelastic
- ◇ Newtonian
- – – Analytical viscoelastic with slip length 2nm
- – – Analytical viscoelastic

$$Q = \pi f T$$

Q = Quality factor
f = Vibrational resonant frequency
T = Time constant for vibrational damping

**Standard assumptions in the fluid mechanics of simple liquids – a purely viscous response and the no-slip boundary condition – must be revisited at short length scales and fast time scales.**

[1] M. Pelton et al., Nat. Nanotechnology. **4**, 492 (2009)

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