

A sophisticated research instrument for directly measuring static and dynamic forces between surfaces (inorganic, organic, metal, oxide, polymer, glasses, biological, etc.) and for studying interfacial and thin film phenomena at the molecular level. Modular design allows for expansion with numerous attachments and customized upgrades (see page 3).



*designed by Jacob Israelachvili*

## APPLICATIONS

Research areas and types of interactions that can be directly measured \*

**Dispersion science** – “colloidal” forces between surfaces in liquids and controlled vapors

**Adhesion science** – long-range colloidal forces and short-range adhesion forces

**Surface chemistry** – surface and electrochemical interactions between dissimilar materials

**Detergency, food research** – forces between surfactant and lipid monolayers and bilayers

**Biomaterials and biosurfaces** – forces between protein and polymer-coated surfaces

**Biomedical interactions** – ligand-receptor, protein and model biomembrane interactions

**Tribology** – friction, lubrication and wear of smooth or rough surfaces, thin film rheology

**Powder technology** – capillary effects and surface deformations during interactions

**Materials research** – mechanical and failure properties of metal and oxide surfaces and films

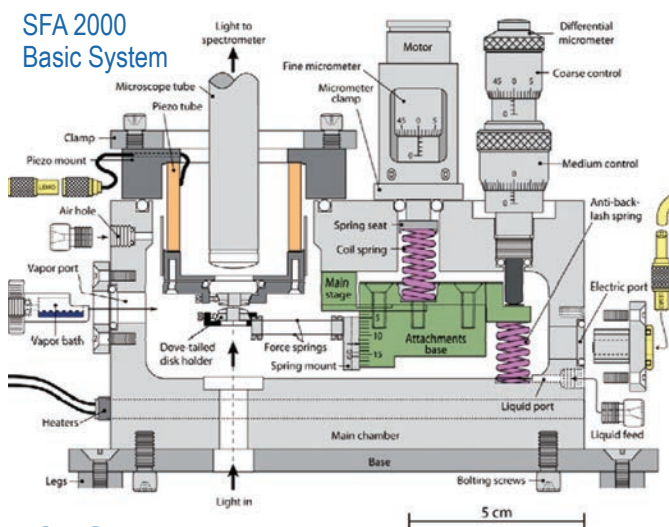
*\* This list is not exhaustive; contact us for your specific needs.*

## GENERAL DESCRIPTION

The SFA measures forces between two surfaces in vapors or liquids with a sensitivity of a few nN and a distance resolution of 1 Å (0.1 nm). It can also measure the refractive index of the medium between the surfaces, adsorption isotherms, capillary condensation, surface deformations arising from surface forces, dynamic interactions such as viscoelastic and frictional forces, thin film rheology, and other time-dependent phenomena in real time at the molecular (nano-) scale. The molecularly smooth surfaces of hard materials such as mica, silica, sapphire, polymers, serve as suitable substrate surfaces in most measurements; these can also be coated with thick or thin layers of surfactants, lipids, polymers, metals, metal oxides, proteins and other biomolecules.

## HOW IT WORKS

The figure below is a schematic drawing of the SFA 2000 configured with the Piezoelectric Top Mount (attached to the exterior of the Main Chamber and hosts the top surface) and the Main Translation Stage Bottom Mount (resides inside the Main Chamber and hosts the bottom surface) ready for use. For both the SFA 2000 and  $\mu$ SFA, the shapes of the interacting surfaces, the absolute separation between them, and the thickness of any adsorbed layer on the surfaces, are measured (to within 0.1 nm) by analyzing the optical interference fringes (known as FECO fringes) produced when white light passes through the two surfaces. The distance between the surfaces is controlled by a four-stage mechanism of increasing sensitivity from millimeters to ångströms. Using the SFA 2000, dynamic measurements are conducted with surfaces in motion (vertically, horizontally, or in any direction in 3D space) using one of the attachments described in the following pages, while for the  $\mu$ SFA dynamic measurements are conducted with the surfaces in vertical motion. The  $\mu$ SFA retains the same normal force measurement capability as the SFA 2000 but in a compact form factor for use in typical laboratory microscopes thereby enabling SFA *and* fluorescence studies, for example.



**SFA Control Box**



## USES

The SFA technique is routinely used to characterize and quantify various types of interactions between surfaces in liquids and vapors (see references on page 4). Static interactions include van der Waals and electrostatic forces, forces due to solvent structure (solvation and hydration forces), capillary forces, hydrophobic interactions, polymer-mediated steric and depletion forces, surfactant monolayers and lipid bilayers, adhesion and bio-specific receptor/ligand or other "lock-and-key" type binding interactions. Dynamic and time-dependent interactions include the viscosity of liquids in ultra-thin films (nano-rheology), slow relaxations of liquids, and polymers in confined geometries, and surface deformations during the approach, separation and lateral sliding of two surfaces. More recent applications have included food technology, the friction of clutches, how geckos run on walls and ceilings, the bioadhesion of mussels, joint biolubrication.

## MAIN FEATURES AND ATTACHMENTS

For anyone who wants to accurately measure the forces or any type of “interaction” between two material surfaces at any given separation in air, vapor or liquid, including their local geometry (shape) and deformations, the SFA stands unrivalled as to directness of measurement and visualization, unambiguous (sub-ångstrom) accuracy, and stability to thermal drift. Unlike some surface force-measuring instruments, such as scanning probe microscopes and pin-on-disk tribometers, the SFA 2000, especially when used with FECO optics, measures forces between surfaces at precisely known surface separations, providing the local surface geometry (shape), directly at the point of interaction. A number of capabilities that appeared as accessories in earlier models (such as the SFA 3) are now part of the SFA 2000, and new attachments allow for various dynamic measurements to be made, for example, of friction, lubrication and viscoelastic forces over a large range of speeds or shear rates. Some of these capabilities are illustrated below:

### FRICITION SENSOR/ACTUATOR ASSEMBLIES

*For friction and lubrication studies*



*1D Sense & Actuation*



*2D/3D Sensing*



*3D Sense & Actuation*

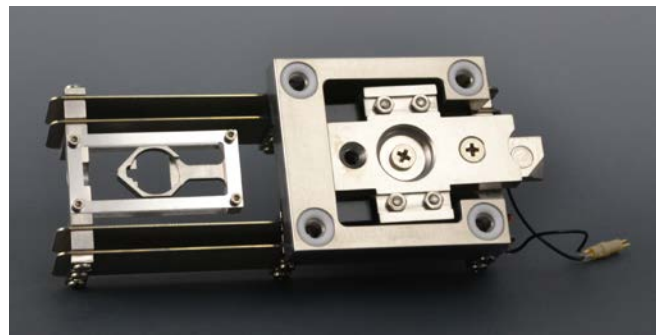
### BIMORPH VIBRATOR

*For measuring thin-film viscosity*



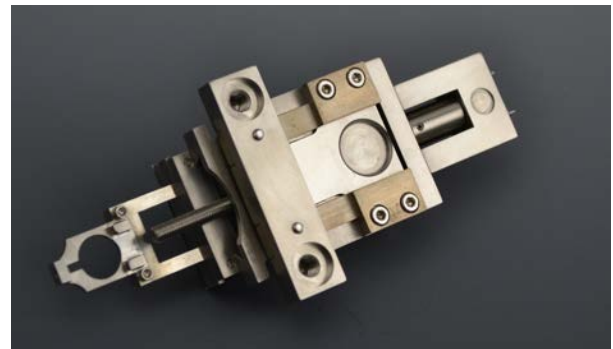
### PIEZOELECTRIC BIMORPH SLIDER (1D & 2D)

*For high-speed shearing of thin films*



### VARIABLE MAIN STAGE SPRING

*For multiple in-situ selectable spring stiffnesses*



### CUSTOM ATTACHMENTS

*Designed for your specific research*



## OTHER ATTACHMENTS INCLUDE:

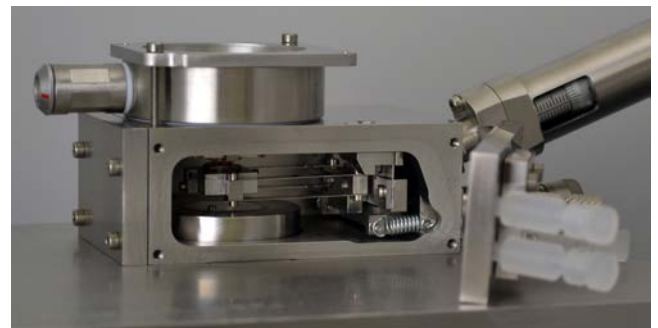
(1) Variable Stiffness Force-Measuring stage, (2) Constant Force-Measuring Balance, (3) Attachments for moving and detecting forces in 3D, (4) High-Speed Friction attachment (pin-on-disk type), (5) Attachments for applying electric or magnetic fields, (6) Short Working Distance for in-situ fluorescence & FRAP measurements (FL-SFA), (7) Attachment for electrochemical studies (EC-SFA), (8) Under-Water Mounts for biological surfaces

## MAIN FEATURES AND ATTACHMENTS

The microscope-ready SFA, or  $\mu$ SFA, is intended to be used in typical upright laboratory microscopes. Instead of an external white-light source, the microscope itself provides the broad-band light (tungsten, 75W minimum) as well as the light collection and redirection to a side exit port for external guiding to a spectrometer to generate the FECO (Fringes of Equal Chromatic Order) measure of the inter-surface separation and *contact geometry*. This allows common modern microscopy, such as fluorescence imaging, to be done with the SFA. The  $\mu$ SFA supports large diameter, short focal-length objectives (< 36MM diameter and working distance > 11MM). The  $\mu$ SFA, like the SFA2000, especially when used with FECO optics, measures forces between surfaces at *precisely* known surface separations (piezoelectric control of 0.75 nm/V, and fine-motor control at 3 nm/sec for 3.0 V<sub>app</sub>), providing the local *surface geometry* directly at the point of interaction. The  $\mu$ SFA uses the same surfaces as the SFA2000 and can be used in an SFA2000 optical setup.



*designed by Jacob Israelachvili*



*Corrosion resistant 316 Stainless Steel with ports for filling and emptying, temperature monitoring (thermister) and chamber heating (optional).*



*Can also be used in an SFA2000 Optical Setup*

### SFA DISKS / MICA

*Various center thicknesses and radius of curvatures (RoC) available.*



### SFA ACCESSORIES Mica Cutting Stage & Miniature Hot Plate



ASK ABOUT OUR

**SFA BOOTCAMP**

\*NEW USER\* TRAINING

## FUTURE ATTACHMENTS TO INCLUDE:

(1) 1D Bimorph Slider, (2) 1D Friction Device, (3) Attachment for electrochemical studies (EC- $\mu$ SFA), and (4) Under-Water Mounts for biological surfaces.

## THE SFA AND FECO OPTICAL TECHNIQUE AND INTERFACING WITH OTHER TECHNIQUES

**Recent advances in the surface forces apparatus (SFA) Technique.** J Israelachvili, et al., *Reports on Progress in Physics* (2010) 73 1-16.

Contact electrification and Adhesion between dissimilar materials. R.G. Horn and D.T. Smith, *Science* (1992) 256 362.

Interactions of silica surfaces. G. Vigil et al., *J. Colloid and Interface Science* (1994) 165 367.

Topographic information from multiple beam interferometry (MBI) in the SFA. M. Heuberger et al., *Langmuir* (1997) 13 3839-3848.

The x-ray SFA for simul. x-ray diffraction & direct normal and lateral force measurements. Y. Golan et al., *Rev. Sci. Instr.*, (2002), 73, 2486-2488.

The extended SFA. Part III. High-speed interferometric distance measurement. Zach et al., *Rev. of Sci. Instr.* (2003) 74 260-266.

Extending the SFA capabilities by using white light interferometry in reflection. Conner, J. N. & R. G. Horn, *Rev. of Sci. Instr.* (2003), 74, 4601-4606.

3D Force and Displacement Sensor for SFA and AFM measurements. Kai Kristiansen et al., *Langmuir* (2008); 24(4); 1541-1549.

The electrochemical SFA: The effect of surface roughness, electrostatic surface potentials and anodic oxide growth on interactions forces and friction between dissimilar surfaces in aqueous solutions. Valtiner et al., *Langmuir* (2012) 28 (36) 13080-13093.

The intersection of interfacial forces and electrochemical reactions. Israelachvili et al., *JPCB* (2013) 177 (51) 16369-16387.

Interferometry of surfaces with well-defined topography in the SFA. Gupta & Frechette, *J. Colloid. & Interf. Sci.*, (2013), 412, 82-88.

Surface-initiated self-healing of polymers in aqueous media. Ahn et al., *Nature Materials* (2014) 13 867-872.

Analyzing refractive index profiles of confined fluids by interferometry. Kienle & Kuhl, *Analytical Chem.*, (2014), 86, 11860-11867.

Real-time MBI reveals complex deformations of metal-organic-framework upon humidity adsorption/desorption. Baimpos et al., *J. Phys. Chem.* (2015), 119, 16769-16776.

Real-Time Monitoring of Aluminum Crevice Corrosion and Its Inhibition by Vanadates with MBI in a SFA. Shrestha et al., *J. Electrochem. Soc.* (2015) 162 (7) C327-C332.

## COLLOIDAL, POLYMER AND ADHESION INTERACTIONS

**Intermolecular and Surface Forces (3rd Ed).** J Israelachvili, *Elsevier & Academic Press*, 2010.

Debye length and double-layer forces in polyelectrolyte solutions. Tadmor et al., *Macromolecules* (2002) 35 (6) 2380-2388.

Evaporation and instabilities of microscopic capillary bridges. Maeda et al., *PNAS* (2003) 100 (3) 803-808.

Transient Interfacial Patterns and Instabilities Associated with Liquid Film Adhesion and Spreading. H. Zeng et al., *Langmuir* (2007) 23 6126-6135.

Recent advances in gecko adhesion and friction mechanisms and development of gecko-inspired dry adhesive surfaces. Zhou et al., *Friction* (2013) 1(2): 114-129.

Long-range electrostatic screening in ionic liquids. Gebbie et al., *PNAS* (2015) 112 (24) 7432-7437.

Structure of Polyelectrolyte Brushes in the Presence of Multivalent Counterions. Yu et al., *Macromolecules*, (2016), 49, 5609-5617

Long range electrostatic forces in ionic liquids: controversies and opportunities. Gebbie et al., *Chem. Commun.*, (2017), 53, 1214-1224.

Tuning underwater adhesion with cation- $\pi$  interactions. Gebbie et al., *Nature Chemistry* (published online 13 Feb 2017).

## BIOLOGICAL AND BIOMEDICAL INTERACTIONS

**Design Rules for Biomolecular Adhesion: Lessons from Force Measurements.** Deborah Leckband, *Annual Review of Chemical and Biomolecular Engineering*, (2010) 1, 365-389.

Direct measurement of a tethered ligand-receptor interaction potential. J. Y. Wong et al., *Science* (1997) 275 820-822.

Thin film morphology and tribology of food emulsions: a study of three mayonnaise samples. S. Giasson et al., *J. Food Science* (1997) 62 640-652.

Impact of polymer tether length on multiple ligand-receptor bond formation. Jeppesen et al., *Science* (2001) 293 465-468.

Interaction forces and adhesion of supported myelin lipid bilayers modulated by myelin basic protein. Min et al., *PNAS* (2009) 106 3154-3159.

Dynamics of force generation by confined actin filaments. Banquy et al., *Soft Matter* (2013) 9 2389-2392.

Stick-slip friction and wear of articular joints. Lee et al., *PNAS* (2013) 110 (7) E567-E574.

SFA and its applications for nanomechanics of underwater adhesives, Xris Oh et al., *Korean J. Chem. Eng.*, (2014), 13, 1306-1315./

Developing a general interaction potential for hydrophobic and hydrophilic interactions. Donaldson et al., *Langmuir* (2015) 31 (7) 2051-64.

## DYNAMIC, RHEOLOGICAL AND TRIBOLOGICAL INTERACTIONS

**Surface Forces and Nanorheology of Molecularly Thin Films.** Marina Ruths and Jacob N. Israelachvili, in *Handbook of Nanotechnology* 3rd edition, Chapter 29, B. Bushan Ed., *Springer-Verlag*, (2010) 857-922.

Surface forces and viscosity of water measured between silica sheets. R.G Horn et al., *Chem Phys Lett* (1989) 162 404.

Thin film rheology and tribology of confined polymer melts: contrasts with bulk properties. G. Luengo, et al., *Macromolecules* (1997) 30 2482-2494.

Triboelectrification between smooth metal surfaces coated with SAMs. Akbulut et al., *J. of Phys. Chem. B* (2006), 110(44) 22271-22278.

On the conformational state of molecules in molecularly thin shearing films. J. Israelachvili & C. Drummond, *PNAS* 112 (2015) (36) E4973.

Time-dependent wetting behavior of PDMS surfaces with bio-inspired, hierarchical structures. Mishra et al., *ACS Applied Materials & Interfaces* (2016) 8 (12) 8168-8174.