into the processes leading to strain-induced second-harmonic enhancement in waveguide structures would be of high interest to the community.

The effect of highly efficient second-harmonic generation in strained silicon waveguides provides a new method for the creation of active silicon photonic devices, adding functionalities to our already available arsenal such as wavelength generation and conversion. These will be central functions in integrated multi-wavelength communications and integrated signal processing in future devices. ❐

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COLLOIDAL FRICTION

Kinks in motion

The ability of laser interference potentials to trap and control colloidal particles opens up a new potential area of 'toy systems' displaying real physics. A beautiful example is the study of friction between colloidal crystals and a variety of artificially created surface potentials.

Andrea Vanossi and Erio Tosatti

One of the greatest challenges of physicists, particularly condensed-matter physicists, has always been the difficulty of describing nature's complex systems with simple, mathematically solvable models. Even in those rare cases where such a goal may be realized, the physical properties of real materials are not easily changed, thus limiting the possibility of testing theoretical predictions fully.

Such limitations are particularly challenging in the field of friction[1] — the process of irreversibly converting the mechanical energy of motion into heat — a fascinating and complex topic where physics, chemistry, engineering and materials science meet. Although progress over the centuries has led to the formulation of the phenomenological laws of tribology, many key aspects and mechanisms of the multifaceted nature of microscopic friction still lack fundamental understanding, and increasingly call for well-designed experiments at well-characterized interfaces. So far, atomic force microscopy and modelling, as well as atomistic molecular dynamics simulations[2], are aiding understanding at the nanoscale level. For friction at the mesoscopic and larger scales, our knowledge is still limited. This is because, despite the historical contributions of surface force apparatuses and quartz crystal microbalances, there are still many aspects of friction that specifically occur at the micrometre scale and above that are poorly understood; for example, those connected to multiscale complexity at the interface and to slow relaxations and ageing.

However, the field of friction can now benefit from the opportunities offered by trapping and handling nanoparticles with potentials artificially created by interfering lasers; a technique originally applied to cold atoms[3]. Writing in *Nature Materials*, Bohlein and colleagues[4] show how colloidal particle crystals — charged polystyrene spheres in their case — trapped in laser interference fields can cast new light on elementary frictional processes in ideally controlled sliding systems. Colloidal crystallized layers that are forced to slide by Stokes forces in the presence of a laser-generated static potential are an exceptionally versatile tool. Unlike crystalline or quasicrystalline substrates of conventional sliding friction, the potential can now be controlled (Fig. 1). This mimics for example two-dimensional (2D) lattices with different symmetries, variable lattice spacing and corrugation amplitudes, and potentially realizes different types of commensurate and incommensurate interfaces, as well as quasicrystal substrate geometries. In addition, using the method of Bohlein and colleagues, it may be possible to investigate colloidal paramagnetic particles in which the pair interaction can be easily varied, thus leading to different frictional responses. Another possibility could be to use the diverse viscous nature of the suspending fluid to study the effect of changing the damping coefficient on the dissipative dynamics.

Colloidal friction provides an unprecedented real-time insight into the basic dynamical mechanisms at play. Unlike atomic force microscopy, surface force apparatuses and quartz crystal microbalances — which provide averaged frictional data, such as the overall static

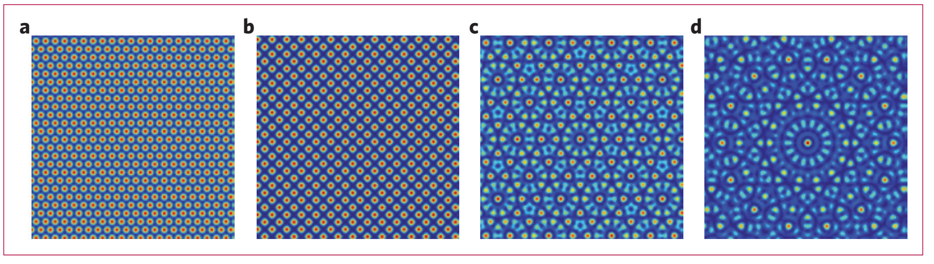

Figure 1 | Extraordinary substrate geometries obtained by interfering laser beams. The external potentials are created by interfering laser beams with a specific symmetric arrangement: periodic, triangular (**a**) and square (**b**); quasiperiodic, decagonal (**c**) and tetradecagonal (**d**). Optical lattices may be realized by the interference pattern of three, four, five or seven laser beams. The exceptional versatility of the approach allows different lattice spacings and corrugation amplitudes, as well as distinct substrate geometries, to be considered; paramagnetic colloidal systems may also be exploited so that the pair–particle interaction can be varied easily.

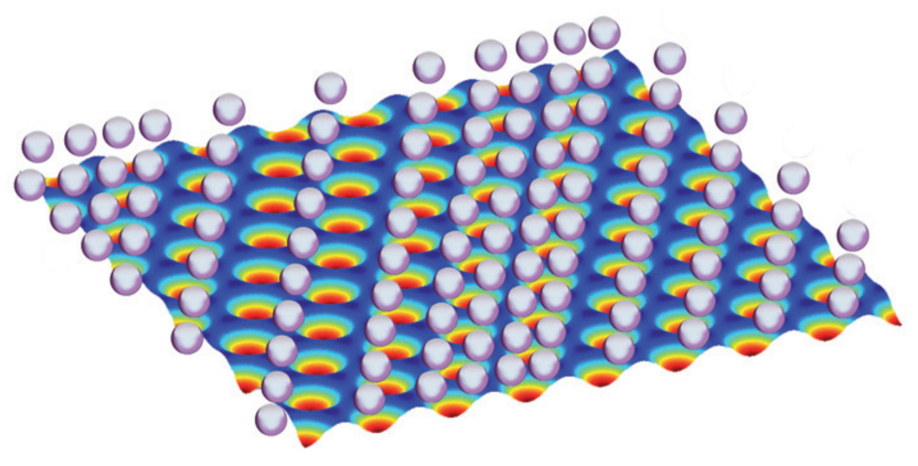

Figure 2 | Soliton superstructures of sliding colloidal particles. The frictional dynamics of a charged colloidal monolayer driven across these substrate potentials exhibit the formation of propagating kink-like structures.

and kinetic friction, mean velocities and slip times — the colloidal experiments observe the true motion of every individual particle with time during sliding. This has so far been restricted to the ideal world of molecular dynamics simulations[5]. Transitions between different dynamical states may become experimentally accessible and can be analysed and related to the detailed particle motion.

The observation of Bohlein and colleagues[4] of moving 'kinks' and 'antikinks' in colloidal monolayers driven across a periodic potential raises an interesting frictional issue, providing experimental evidence of the role played by 2D misfit dislocations — localized soliton-like superstructures (often called 'kinks' and 'antikinks'; Fig. 2) — in the sliding dynamics of a system under shear. In general, kinks give rise to 2D Moiré patterns; shadow-like periodic modulations that form, for example, at crystalline overlayers that are out of registry with their substrates. Kinks and antikinks — physically corresponding to localized compressions and expansions in the particle array density — are relevant in the context of friction, because according to theory and simulations[6,7] they constitute the real mobile sliding objects as opposed to the single particles, which have reduced motion.

Bohlein and colleagues demonstrate the dynamics of these mobile kinks by driving the highly charged polystyrene spheres — which naturally form a 2D triangular crystal in water in the presence of gravitational and optical forces — across commensurate and incommensurate laser-generated substrate potential geometries. External forces were applied to the colloidal monolayer by mounting the sample cell on a piezo table so that it was able to move laterally with nanometre accuracy: moving at a given velocity leads to a viscous Stokes force acting on each particle. Bohlein and co-workers show that the system's frictional response is then characterized by the average colloidal velocity as a function of the applied driving force.

Although this work begins to address systematically the issues of static friction, depinning and nonlinear sliding dynamics with unique real-time insight, much still remains to be explored. Indeed, the non-equilibrium dynamics of nonlinear systems with many degrees of freedom that are pinned in some external potential — often a central issue in many solid-state physics problems — exhibits a variety of complex spatial and temporal behaviours. A common feature is a strongly nonlinear mobility: if an external field is applied to the array of particles, its average system velocity is zero below some usually well-defined threshold, and non-zero above it. In general, the mobility is a highly nonlinear function of the applied force.

As proved in the framework of driven Frenkel–Kontorova-like models[8] — which describe the dissipative dynamics of a system of sheared interacting particles over a rigid substrate potential — at low external fields, sliding is governed by mechanisms that can be identified as motion of kink-like structures, whereas at high rates or stresses, systems usually slide smoothly without feeling the substrate corrugation. The detailed scenario may depend crucially on the interface commensurability and interactions.

By tuning the substrate lattice spacing, and keeping the laser intensity and the colloidal spacing constant, Bohlein and co-workers investigate, in real-time monitored by video microscopy, the features of the propagating kink structures in determining the different dynamical states in the force–velocity characteristics. The authors show, in agreement with Aubry's theory of the Frenkel–Kontorova model[9], the importance of interface incommensurability to observe frictionless — or superlubric — regimes, where static friction turns from finite to vanishing by moving from a commensurate colloidal contact towards an incommensurate stiff one. They also plan the sliding of colloidal monolayers over ordered yet non-periodic surface potentials, where the particles seem to preferentially follow novel, curved trajectories along substrate motives exhibiting the typical ten-fold rotational symmetry of quasicrystals (Fig. 1c), and where the system dynamics again shows evidence of solitonic superstructures.

The possible future implications and potential of this technique seem diverse. The colloidal crystal sizes can be increased to address and study mesoscopic complexity. The trapping-and-driving method could be used to introduce stick-slip — the truly fundamental element of sliding friction. Yet other techniques might be designed to introduce slow relaxations and ageing; ingredients that are crucial to macroscopic friction. Indeed, it would be wonderful if we could look inside the millimetre-sized shell of a trapped colloid in water and uncover some of the secrets that determine both the scratching of our windscreen wipers and the sliding of tectonic plates during an earthquake. ❒

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