scattering has been observed⁸, although it is much weaker than in magnetically anisotropic higher-spin systems, where it dominates.

On the other hand, much remains to be done to elucidate the evolution of the magnetic state as charge carriers are introduced by doping or varying the oxygen content. It is important to confirm the current trends and accumulate the evidence to show that the local moments really do persist into the superconducting phase. One thing is clear; the magnetism cannot be ignored. It surely is the reason why the charge carrier density is so low,

and even quenching of the moments would have specific implications for the nature of the superconducting state. □

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V.J. Emery is at Brookhaven National Laboratory, New York 11973, USA.

Surface science

Methods of time-resolved study

David A. King

REAL-TIME surface spectroscopic studies would be invaluable for the investigation of the many dynamic phenomena that occur on surfaces. H.E. Elsayed-Ali and G.A. Mourou now report (*Appl. Phys. Lett.* **52**, 103–104; 1988) a reflection high-energy electron-diffraction (RHEED) pattern obtained from the cleaved surface of a sodium chloride crystal using a single 200-picosecond (ps) electron pulse (Fig. 1). Although the inherent repeat time in their experiment is limited by the detectors they use — a phosphor screen with a persistence time of 0.15 ms and a microchannel plate with an even longer dead time — this type of development heralds a new generation of tools for surface science.

The relatively slow development of time-resolved techniques in surface science has a simple explanation. There are only about 10^{15} atoms or molecules (10^{-9} moles) cm^{-2} at a well-defined surface available to the experimentalist. Although a wide range of particle-based techniques have now been developed using combinations of electron, photons, ions and atoms

as incident and exit particles, intense particle sources are often needed simply to obtain sufficient sensitivity to detect surface species. Some techniques have very limited surface sensitivity except under restrictive conditions: for example, X-ray diffraction is useful only with close to grazing incidence. But because electrons with energies of 50–3,000 eV have mean free paths of only a few atomic diameters in solids, techniques based on detecting exit electrons are sensitive only to those electrons that are generated near the surface of the solid and have a well-defined energy.

For example, low-energy electron diffraction (LEED) operating at 50–300 eV, is inherently surface-sensitive, and is a strong candidate for time-resolved studies. This technique was applied a few years ago (Becker, R.S., Higashi, G.S. & Golovchenko, J.A. *Phys. Rev. Lett.* **52**, 307–310; 1984) to the study of the dynamics of laser annealing of germanium. But at these low electron-beam energies, the current is space-charge limited (Coulomb repulsion between the electrons causes the beam to diverge), and it has been estimated that only one electron is reflected from the surface for each nanosecond shot.

For the study of adsorbates on surfaces, vibrational spectroscopy offers exciting possibilities, given the wealth of information that it provides. One such method however, high-resolution electron-energy-loss spectroscopy (HREELS), is usually operated at lower electron energies than LEED, and therefore runs into the same limitations on beam current. The best time

resolution achieved with this technique to date (Dubois, L.H., Ellis, T.H., Zegarski, B.R. & Kevan, S.D. *Surf. Sci.* **172**, 385–397; 1986) is 5 ms at constant frequency. Predictions of spectral scans with millisecond time resolution in HREELS have not yet been realized. Reflection-absorption infrared spectroscopy (RAIRS) offers greater potential, although the inherent noisiness of tunable infrared lasers limits its present use. Absorption bands are weak and easily lost in the noise. The best time resolution to date with RAIRS (30 ms) has been obtained with a Fourier-transform instrument, with a traditional black-body infrared source (Chesters, M. *J. elec. Spec. Related Phen.* **38**, 123–140; 1986).

In the new system described by Elsayed-Ali and Mourou, the 25-keV electron source is a photocathode, composed of a gold film deposited onto a sapphire window, activated by pulsed ultraviolet light from a YAG laser (Fig. 2). For studies of dynamic events, this source provides a good pulse width (about 150 ps) and beam current (5×10^5 electrons per pulse), but the maximum repetition rate is limited by the detectors to 1.5 kHz. Further develop-

Fig. 2 Schematic diagram of the system used by Elsayed-Ali and Mourou for time-resolved studies of crystal surfaces. A picosecond laser pulse excites a pulse of electrons from the photocathode, which is accelerated, focused and scattered off the sample surface.

ments in rapid detection are necessary for repetitive studies of dynamic events.

The immediate need for real-time surface techniques arises from the important development of pulsed laser processing of metals and semiconductors, and the need to monitor the transformations in these materials. But the whole field of dynamics at surfaces, including surface melting and roughening, surface diffusion, local density and structural fluctuations, the formation of metastable adsorbate states and short-lived catalytic intermediates, is ripe for detailed study once these techniques become available. In studies of adsorbates, pulsed laser time-of-flight mass spectrometry and secondary ion mass spectrometry hold great promise, particularly in conjunction with pulsed molecular beam sources. For alloy systems, ion-scattering spectroscopies could be developed with the availability of intense, pulsed ion sources. For structural studies, RHEED is currently the leading contender. □

David A. King is in the Department of Physical Chemistry, Cambridge University, Lensfield Road, Cambridge CB2 1EP, UK.

Fig. 1 Reflection high-energy electron diffraction patterns from a cleaved surface of a sodium chloride crystal recorded with a microchannel plate. a, Using a single 200-ps electron pulse; b, averaged over 50 pulses. (From Elsayed-Ali and Mourou.)