analyser. By careful adjustment of the carrier wave symmetry (a simple balanced demodulator is used) breakthrough was kept at least 50 dB below maximum signal level. Total harmonic distortion was −30 dB and a signal-to-noise ratio of 40 dB was obtained. The possibility of cross modulation between successive tracks was investigated by recording pulses with a repetition rate one-third that of the field frequency. On playback each recorded pulse was then followed by two blank fields so that any cross modulation could be observed. The level of cross modulation from a signal of maximum amplitude was found to be below noise level in both the standard and 'stop'-playback modes.

In analysing stress-wave emissions it is often required to count (after recording) the total number of events that have occurred. A typical testing sequence may run for 30 min and give upwards of 10^4 events. During counting it is essential, of course, that the number of spurious signals, due to tape drop-out and mains-borne interference, should be negligible. Test runs, made from a clean tape, with the counter sensitivity set just above background noise level, gave an average of 700 spurious counts in 30 min. This was reduced to an average of 250 counts by incorporating a mains frequency filter in the recorder's supply line. A similar test run conducted on an unmodified recorder would give more than 9×10^4 counts due predominantly, of course, to the presence of head switching pulses.

Test recordings made of a 50 kHz sinusoidal signal and a typical wideband ultrasonic pulse are shown in figure 11. Head switching pulses are completely suppressed during the blanking period which results in an overall dead time of $\approx 0{\cdot}25\,\%$ of total run time. Satisfactory operation of the motor speed servomechanism was obtained, the normal lock-in time of 2–3 s being achieved.

4 Conclusion

It has been shown that, by suitable modifications, a VTR can be used for satisfactory recording of wideband, non-TV-format signals. A wider bandwidth (up to about 3 MHz) is possible with the modified 1100 SL machine if high-density chromium dioxide tape is used (Dare 1975, Sanyo Marubeni (UK) Ltd, private communication).

One great advantage of the Sanyo recorder is the 'stop' facility. This enables a transient event (of up to 20 ms) to be 'looped' directly, thereby facilitating subsequent analogue signal processing, such as frequency analysis using a spectrum analyser.

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A helium metastable source for surface spectroscopy

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Abstract A compact, high-intensity helium metastable source is described for use in surface spectroscopy experiments. This source, based on electron bombardment of a helium beam, produces a helium metastable flux of 4×10^{14} atoms s^{-1} sr^{-1}, with a stability of 2%, and an effective ultraviolet photon content of less than 1%. Preliminary results, obtained from the study of the nickel (100) surface with this source, are presented and indicate that the metastable atoms are de-excited by a one-electron process.

1 Introduction

In recent years there have been many advances in our understanding of the structure and properties of metal surfaces as a consequence of the widespread application of new techniques. One of these techniques, which has played an important role in elucidating the electronic structure of adsorbates on metal surfaces, is that of ion neutralization spectroscopy (INS) (Hagstrum 1954).

In this technique, the surface of a metal is probed by a very low-energy (5–10 eV) beam of rare gas ions, typically (but not necessarily) helium. When the rare gas ion is close to the metal surface a two-electron, Auger-type process occurs in which one electron from the Fermi sea neutralizes the ion and a further electron is ejected from the metal carrying the balance of the available energy.

That this is a true surface process has been demonstrated by Heine (1966) and Wenass and Howsman (1968). The metal electrons involved in the neutralization process originate from the region in which the metal electron wave function tail, outside the metal surface, overlaps with the wave function of the ion. In this respect, INS may be considered a superior technique to ultraviolet photon spectroscopy (UPS), which has no surface restriction of this sort.

The ejected electron probes the metal surface and measurements of the energy spectra of the ejected electrons contain information on the electronic states at the metal surface. The ejected electrons are of low energy, typically lying between 0 and 15 eV. Despite the fact that the incident ions are of low energy, the ejected-electron energy spectra are energy-broadened and extrapolation to the ejected-electron energy spectra corresponding to the incidence of zero-energy ions is necessary before the data can be deconvoluted.

A modification of INS proposed by Delchar and MacLennan (1969) utilizes helium metastables, instead of low-energy helium ions, to probe the metal surface. The advantages foreseen for this use of the metastable atom as an intermediate are manifold. Firstly, since the helium metastable levels (2^1S at 20·6 eV and 2^3S at 19·8 eV above the ground state) lie above the top of the Fermi sea of the metal, there are vacant levels to accept the excited electron which may tunnel into the metal when the metastable atom is sufficiently close to the metal surface. This results in the formation of a helium ion immediately adjacent to the metal surface, with essentially only its thermal energy ($\frac{1}{40}$ eV at room temperature) plus a small contribution from the image potential.

By this route, ions of almost zero energy may be produced so that the energy spectra of the ejected electrons should contain virtually no energy broadening. A second advantage is the fact that the surface is not now subject to bombardment by energetic ions so that sensitive molecules adsorbed on the metal surface may be examined. Thirdly, in common with straightforward INS, it is only the surface properties which are probed. In some instances, it seems likely that the incident metastable atom is de-excited by collision (Shibata *et al* 1975, Allison *et al* 1972) and in these cases a fourth advantage appears, namely that the process is a one-electron process and the data are not self-convoluted as they are for the two-electron, Auger neutralization process.

Whilst the use of the metastable intermediate route looks attractive, it cannot be fully exploited without a high-intensity metastable source. This is necessary because the overall yield of ejected electrons is a function of the metastable beam intensity, and the efficiency of the ejection process can be as low as 10%. This figure varies for differing metals and adsorbates.

Helium metastable atoms are most conveniently formed by electron bombardment with electrons of the appropriate energy. However, it is not possible to construct a high-intensity metastable source merely by using a high helium pressure, since this simply results in the de-excitation of the metastable atoms by collision. This problem may be overcome by forming the helium atoms into a narrow beam and then allowing electrons of the appropriate energy to move coaxially with the beam. An approach of this kind has been described by Rundel *et al* (1974) who, in addition, employed a magnetic field to constrain the electrons within the envelope of the helium beam. In this way they produced a metastable beam with an intensity of 2×10^{10} atoms s^{-1} sr^{-1} from a source whose overall length was about 35 cm. No figures are given for the ultraviolet photon content of this beam, resulting from the radiative decay at 58·4 nm of the 2^1P state lying 21·2 eV above the ground state.

In the following paragraphs a compact metastable source is described which yields a metastable intensity four orders of magnitude greater than that reported by Rundel *et al*, and with an ultraviolet photon content of less than 1%.

2 The helium source

The neutral helium gas beam is formed by an array of seven stainless steel hypodermic needles, of length 5 mm and ID 0·2 mm, which together form a source of area 0·0113 cm^2 situated at A in figure 1. The length-to-diameter ratio of each tube is 25. The beam of neutral helium atoms emerging from this array of tubes travels towards and along a path coaxial with an electron gun B situated 9 cm away from the tip of the helium source. The cluster of needles is driven from a pressure-controlled helium source stabilized at 13 Pa, whilst the exit side of the helium source and the electron gun are pumped by an oil diffusion pump with a speed of 300 l s^{-1} yielding an operating pressure in the electron gun region of 0·01 Pa.

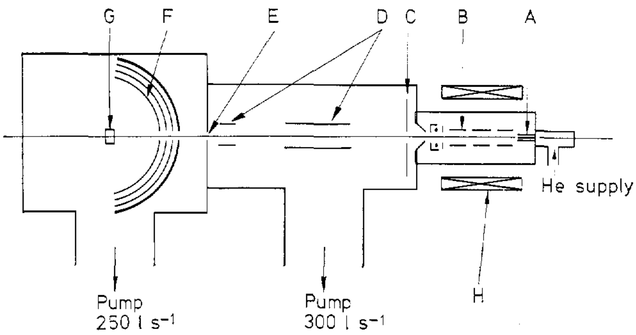

Figure 1 Diagram of the experimental arrangement. A, hypodermic needle helium source; B, electron gun; C, earthed plate; D, ion deflector plates; E, beam-defining aperture; F, hemispherical electron collectors; G, target crystal; H, solenoid

3 The electron gun

The electron gun is shown in cross section in figure 2. The electron source is a single-turn filament F, 6 mm in diameter, made from 0·4 mm diameter thoriated tungsten wire and situated in the centre of a primitive Pierce electrode arrangement E_1, E_2. This single-turn filament is set symmetrically around the axis of the beam and with its plane at right angles to the beam axis. Electrons emitted from this filament pass into an einzel lens, A, B, C, which focuses them onto the axis of the helium neutral beam. All the gun elements are constructed from non-magnetic stainless steel with the first element A of the einzel lens being largely composed of stainless steel mesh to improve the ease of removal of gas from within the lens assembly. The gun elements are supported by ceramic spacers mounted inside a stainless steel tube which is attached by screws to the inner surface of E_2 and is here omitted for clarity. The whole of the combined Pierce electrode and einzel lens arrangement is mounted on the plate G. The focused electron beam travels in the opposite direction to, but coaxial with, the neutral helium beam; this differs from the arrangements of Rundel *et al* (1974) in which both beams travel in the same direction. Any ions formed by electron impact are removed by the deflector plates (D in figure 1) before the metastable beam is finally collimated by an aperture 0·4 mm in diameter (E in figure 1).

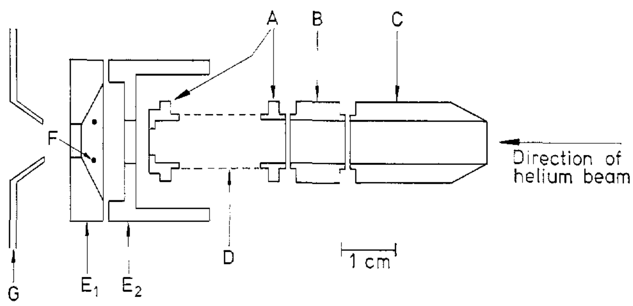

Figure 2 Cross section, drawn to scale, of the complete electron gun, showing A, B and C, elements of the einzel lens; E_1, E_2, Pierce electrodes; F, tungsten filament; G, mounting plate

An additional improvement in the beam intensity (by a factor of two) is obtained by placing a solenoid around the gun assembly. This solenoid provides a magnetic field on the axis of the gun of between 0·01 and 0·02 T. The figures given for the beam intensity were obtained with this field applied. The electrical connections and typical operating potentials of the electron gun are shown schematically in figure 3.

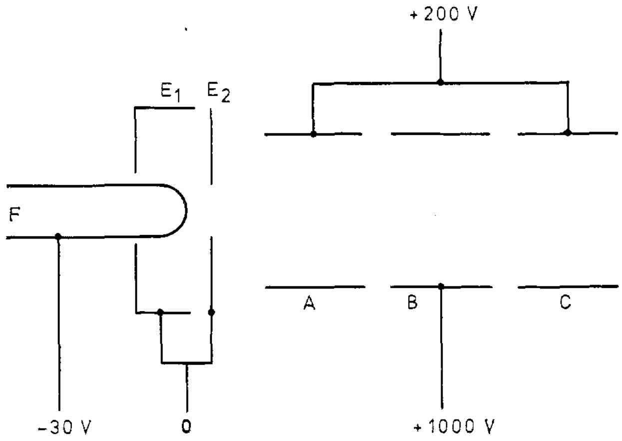

Figure 3 Diagram of electron gun with optimum operating potentials indicated. The letters correspond with those used in figure 2

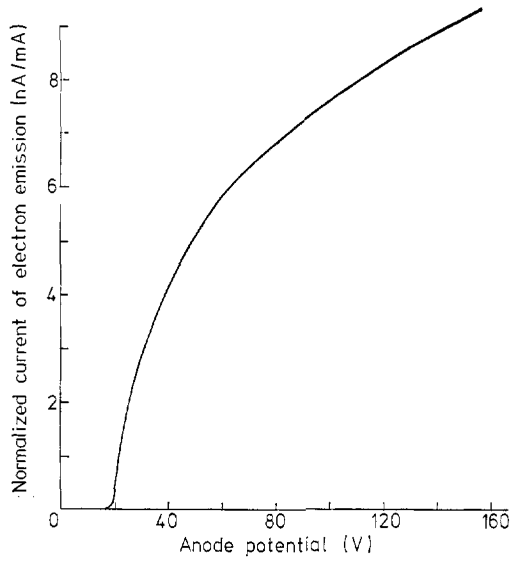

Figure 4 Plot of the normalized ejected-electron current, resulting from the interaction of helium metastables with a tungsten target, as a function of the potential on the first element of the einzel lens

4 Helium metastable detection

The yield of helium metastable atoms was measured by recording the ejected-electron current at a nickel single-crystal target G, placed coaxial with the metastable beam and at the centre of a set of three hemispherical tungsten grids F (figure 1). Measurements of the overall yield of metastable atoms were carried out by recording the current between the nickel target and ground with the nearest of the three tungsten grids at ground. The metastable atom flux was calculated using a figure of 0·17 for the efficiency of the ejection process on nickel. This figure is obtained from the work of Hagstrum and Becker (1967) on the basis that, for the clean nickel surface, the efficiency of the ejection process for low-energy helium ions is the same as that for helium metastables.

The same experimental arrangement, but with different operating potentials on the grids, allowed the energy spectra of the ejected electrons to be measured. For this purpose the target and first grid were earthed whilst the second and third grids were ramped between +5 and −16 V. The collector was held at +18 V to suppress secondary emission. The superposition of a small modulation on the ramp voltage allowed the retarding potential curve to be differentiated electronically and then recorded as energy spectra.

5 Results

In figure 4 is shown a plot of the yield of helium metastable atoms as a function of the electron gun operating conditions. The yield of metastable atoms is in terms of the ejected-electron current leaving the nickel target crystal. The curve shows how the metastable atom flux increases smoothly with accelerating voltage on the first element A of the einzel lens. The voltage ratio of the sections A and B of the lens was maintained at 1 : 5 in this set of readings. Although other voltage ratios were tried, this ratio was found to be particularly suitable. At the highest accelerating potential used, namely 200 V on electrode A, the helium metastable yield reached a value of 4×10^{14} atoms s^{-1} sr^{-1}. The stability of the helium metastable beam, that is, its flux density over an extended period of time, was measured and found to be 2%.

A separate investigation was made to determine the photon flux in the metastable beam, resulting from the radiative decay of the 2^1P state, which lies sufficiently close to the 2^1S and 2^3S states to be excited to a significant extent under the usual gun operating conditions. The photon flux was measured by admitting argon atoms to the experimental chamber to de-excite the helium metastable beam, following Stebbings (1957). The data obtained from these measurements are displayed in figure 5

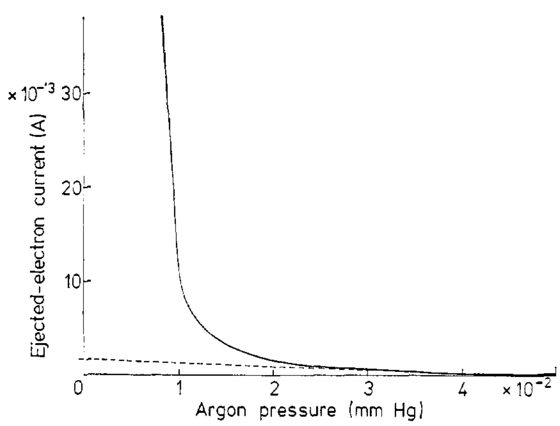

Figure 5 Plot of yield of ejected electrons against pressure of argon added to the experimental chamber. The residual current is that due to photons in the metastable beam (1 mm Hg ≈ 133 Pa)

which shows how the yield of ejected electrons diminished with increasing argon pressure in the experimental chamber, until the only remaining electrons were photoelectrons from the radiative decay of the 2^1P state formed in the gun. The effective photon content of the beam was estimated from the ratio of the current obtained by metastable impact to that obtained when the metastable atoms were quenched. This ratio was $0{\cdot}68 \times 10^{-2}$.

The performance of the helium metastable source, in its intended role as a surface spectroscopy tool, was monitored using a nickel single-crystal target cut to expose its (100) plane. The experimental system was processed to produce a background pressure of $1{\cdot}3\times10^{-8}$ Pa and then the nickel surface was cleaned by argon ion bombardment and annealing, followed by heating in oxygen. Auger spectroscopy revealed that the major contaminants were carbon and sulphur with traces of phosphorus and chlorine. The sulphur, phosphorus and chlorine were removed by ion bombardment and annealing. The ejected-electron spectrum recorded at this stage, that is with carbon present, is displayed in figure 6.

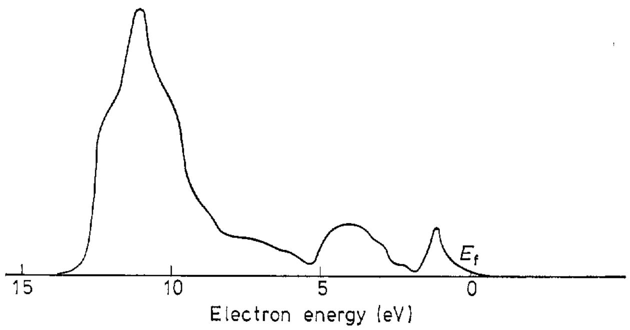

Figure 6 Ejected-electron energy spectrum for helium metastable atoms incident on a Ni (100) surface with carbon present

This spectrum is interesting in that it is clearly not due to a two-electron process, since this would yield a self-convolution of the density of states in nickel and produce an energy spectrum shaped like those obtained by Hagstrum using low-energy ions. Instead, this spectrum is that due to Auger de-excitation of the metastable atom, a one-electron process. The spectrum is very similar in general shape to that obtained by Hagstrum and Becker (1972) after deconvoluting INS data from a nickel (100) surface which had carbon and potassium on it.

It was noticeable that the yield of ejected electrons was a minimum for the clean surface and rose as the surface became contaminated, the yield increasing by a factor of almost five. This suggests that while the efficiency of the metastable de-excitation process may be close to unity for the contaminated surface, it is not so for the clean surface, thus lending support to the efficiency figure of 0·17 already used to calculate the metastable flux.

6 Conclusions

The interaction of a helium metastable beam with a metal surface offers a method of exploring electronic states at metal surfaces without perturbing the metal surface; the method is specific to the metal surface. The metastable source described in this paper provides a significant increase in intensity over sources previously described, yet without any concomitant increase in photon content.

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