Semiautomated Data-Recording and Control System for an Electron Energy Analyzer*

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(Received 20 March 1973)

A description is given of a digital data-recording and control system that has been used with a high resolution low energy electron scattering apparatus for the measurement of characteristic electron energy-loss spectra and Auger-electron spectra of solids (at room and elevated temperatures) and liquids. This system is based on a multichannel analyzer and has the following features: (a) Specimens can be prepared many times with data accumulated in arbitrarily short times after preparation (prior to specimen contamination), and final spectra of high precision can be obtained by summation of individual runs; (b) the voltage sweep applied to the electron energy analyzer can be calibrated dynamically; and (c) data can be accumulated and the target heated by electron bombardment in a cyclic manner with variable accumulation and heating periods. Characteristic loss spectra of tungsten at 800 °C and of liquid aluminum are presented as examples of operation of the system.

INTRODUCTION

We wish to describe a convenient and versatile digital recording and control system (DRACS) that has been successfully operated for several years in conjunction with a high resolution Kuyatt–Simpson electron scattering system.[1,2] The basic experimental objective was the measurement of features of the secondary-electron energy distributions of solids under electron bombardment (in a "reflection" scattering geometry). Specific requirements were: (1) the measurement of characteristic electron energy-loss spectra[3] at low incident electron energies (typically between 50 and 1100 eV) using the beam from a variable-resolution electron monochromator[1]; (2) the measurement of Auger-electron[4] features (at energies typically between 50 and 1100 eV) when the sample was bombarded by electrons with energies of up to about 3 keV; and, (3) measurements of energy-loss spectra and Auger-electron features on samples at elevated temperatures.

It is well known that the attenuation length of electrons in the above-mentioned energy range is less than about 20 Å.[5] Experiments, therefore, have to be performed on well characterized specimen surfaces in an ultrahigh vacuum environment and have to be completed before the specimen surface has deteriorated (whether due to contamination from the residual gas atmosphere or to possible electron beam damage). The available signal (at the desired resolution) in the measurements of energy-loss spectra with the electron monochromator and in some cases of Auger spectra is too small to permit the desired spectral precision to be achieved with readily achievable ultrahigh vacua. It was, therefore, required that many individual runs (each consisting of data acquired immediately after sample preparation) could be combined to achieve an improved signal/noise ratio; in effect, the vacuum in the apparatus could be significantly improved in this way.

A multichannel analyzer has sufficient flexibility to serve as the major element of DRACS. We describe in Sec. I the additional elements required to perform the functions outlined above and in Sec. II we give several examples of the system performance. This system now has the following features.

(a) Following specimen preparation, data can be accumulated for an arbitrarily short time in a section of the analyzer memory; accumulation can then be transferred (automatically, if desired) to another section of the memory, and so on, with the data being punched on paper tape at the end of the cycle. This sequence can be repeated many times, and all data obtained within the specified short interval of time after specimen preparation can be combined. Likewise, other data obtained in similar time intervals can be combined to check for changes in spectral distributions due to possible specimen contamination.

(b) Routine calibration of the channel scale of the analyzer in terms of electron energy (or energy loss) can be accomplished conveniently and dynamically with the use of the analyzer ADC and by reference to a feature of known energy (e.g., the peak due to electrons scattered without energy loss). Alternatively, the channel scale can be calibrated by switching known voltages in series with the voltage sweep applied to the electron energy analyzer to move a feature (e.g., the no-loss peak) along the channel scale.

(c) "Cyclic" modes of operation are possible, in which, alternately, data are accumulated and the specimen is heated by electron bombardment. The data accumulation and heating periods can be independently varied, but both should be short enough, and the thermal inertia of the specimen large enough, to keep the specimen temperature within desired limits.

Use has also been made of orthodox features of the multichannel analyzer in the following ways.

(i) Data is acquired in digital form so that routine processing (e.g., summing of runs, energy-scale calibration, background subtraction, peak location) can be performed by computer. Pulse counting has been employed exclusively to date in the present system, but an analog signal (e.g., from an electrometer or a lock-in amplifier) could be digitized if desired by the analog-to-digital converter (ADC) of the multichannel analyzer.

(ii) Data can be accumulated with many short sweeps rather than one long sweep of the same duration, thereby minimizing low-frequency drifts (e.g., of incident current).[6]

(iii) Digital differentiation of an electron energy distribution can be accomplished, if desired. In addition, with an analog signal input, background subtraction (of value in measurements of Auger-electron spectra) can be readily accomplished using the present voltage sweep waveform (for linear background subtraction) or an auxiliary waveform generator (to represent more complex backgrounds).[7]

I. DESCRIPTION OF SYSTEM

Figure 1 shows a block diagram of the important elements of the system. In all situations described here, the multichannel analyzer is operated in the multiscale mode. On initiation of a sweep, the analyzer advances from channel to channel and, in synchronism, a staircase waveform is generated by a digital-to-analog converter (DAC). This waveform is amplified, with selected gain, and applied with appropriate voltage offsets to the electron energy analyzer as either an energy or an energy-loss sweep. In the present system, pulses from an electron multiplier are counted and stored in channels of the multichannel analyzer that correspond to particular electron energies. The dwell time per channel is here usually a multiple of 400 μsec.

The frequency response of the sweep-voltage amplifier should extend from dc to a sufficiently high frequency such that there is no significant distortion of the staircase waveform at the required sweep rate; the high frequency limit of the amplifier should not be so large, however, as to pass the voltage spikes that occur at the times of channel advance. The sweep amplifier drives a largely capacitive load in the present system, and the maximum sweep rate is limited by the output current capability of the amplifier. This limitation would be reduced with an analyzer having an up–down channel advance capability rather than the up-return-to-zero advance of the present analyzer that generates a saw-tooth-like voltage sweep.

The symbolic switch *S*1 in Fig. 1 is used to determine whether there should be a single sweep, repetitive sweeps, or whether another function should be executed at the end of a sweep (for the "cyclic" mode of operation noted above). In the latter mode, a pulse generator is triggered that controls the duration of separate electron-beam heating of the target. Such heating cannot be performed during data accumulation as the fields associated with the filament heating current and the voltage applied to the filament would distort the trajectories of the low energy electrons being measured and as a spurious electron signal could be generated. During data accumulation, the heating filament and an adjacent shield are grounded, but for heating purposes both elements are connected to a source of variable negative high voltage (with the target usually still at ground). The necessary switching and logic operations are performed here with mercury-wetted relays; such relays are convenient for rapid switching operations and for voltage isolation. The filament current is controlled by a silicon controlled rectifier and the filament voltage by a thyratron from full-wave rectified power sources. During heating, a counting-rate meter used to monitor the average count rate per voltage sweep is gated off so as not to respond to electrons from the heating filament. At the end of the heating pulse, the target is grounded again and another voltage sweep and data-accumulation cycle is initiated. The target temperature is thus determined by the sweep and heat periods and by the heating power. Target heating can be carried out under manual control, if desired. Provision has also been made for temporary interruption of data accumulation (whether the system is in the repetitive sweep or cyclic heating modes) if required; this facility has been found useful in preventing electrical interference associated with the filling of a liquid nitrogen trap.

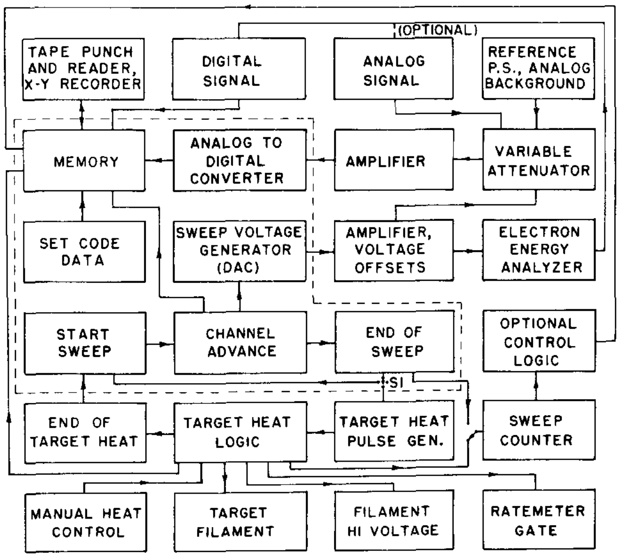

FIG. 1. Block diagram of the important elements of the data recording and control system. Elements contained with the multichannel analyzer are enclosed by the dashed lines.

A binary scaler can be used to count sweeps and to initiate selected functions after a preset number of sweeps has occurred. For example, data can be sequentially accumulated in different sections of the analyzer memory for specified periods. In addition, it is possible in the cyclic mode of operation to accumulate data (and to count sweeps) only after the various controls have been satisfactorily adjusted and the target reached thermal equilibrium. This facility is used to ensure that the system is aligned dynamically by observation of the count-rate meter (to take account of possible thermal movement of the target) and that data are recorded for some number of complete sweeps. It is normally sufficient to monitor the average count rate per voltage sweep but any particular region of the spectral distribution could be monitored by adjustment of the sweep amplitude and offset controls. The first binary stage of the sweep counter could also be used for digital data differentiation by counting additively and then subtractively, and by concurrently switching in and out an appropriate voltage in series with the sweep voltage on alternate sweeps.

The sweep voltage is calibrated dynamically by digitizing it with the analyzer ADC (with use of the attenuator and amplifier shown in Fig. 1 for impedance matching and for most effective use, in range and resolution, of the ADC). It is possible to digitize the sweep voltage once per step (generally near the beginning) or at 400 μsec intervals; in the latter case, an average measure of the step voltage is obtained. The voltage-measuring system consisting of the attenuator, amplifier and ADC is calibrated by digitizing many selected voltages (covering the range of the sweep voltage) from a reference power supply. In the present system, the sweep voltage deviates from linearity by up to about 0.3% of the maximum sweep voltage; this deviation from linearity is taken into account by a small quadratic term in the voltage-versus-channel-number calibration relation determined for each run. The absolute electron energy or energy-loss scale is established by referring the sweep voltage to an analyzer channel corresponding to the peak of elastically scattered electrons in a characteristic loss experiment.[2]

The Auger-electron and characteristic-loss spectral data accumulated in the analyzer memory can be plotted on an $X-Y$ recorder as a laboratory record and punched onto paper tape for subsequent computer analysis. It has been found convenient to punch additional information onto the paper tape (to delineate runs and for indexing and control purposes) and this can be accomplished by setting the appropriate code characters in the analyzer memory with subsequent readout onto the tape in the desired format. A paper tape reader can be used to read spectral data back into the analyzer memory for editing, comparison or summing purposes.

II. SYSTEM PERFORMANCE

Figure 2 shows an energy loss spectrum of a piece of polycrystalline tungsten foil measured with 110 eV incident electrons from the monochromator[1] and with a total electron scattering angle of 20°. The foil was partially cleaned by heating to about 1200°C and the spectrum of Fig. 2 was acquired with the target at a temperature of about 800°C using the cyclic mode of target heating and data accumulation described above; the heating period was 140 msec, the data accumulation period was 200 msec, and 1500 cycles were completed. A feature of Fig. 2 is the prominent loss at about 1.07 eV. Such a loss does not appear to have been observed before[8] although Edwards and Propst[9] detect a weak 1.5 eV loss in loss spectra measured with a W(100) surface. The loss spectrum was not significantly altered after the target was heated to 2000°C.

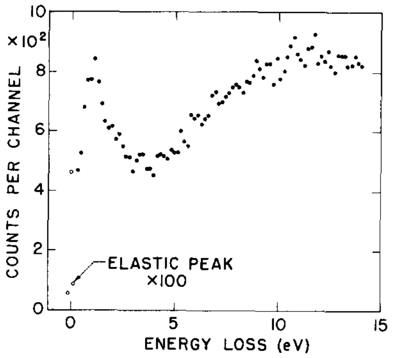

FIG. 2. Characteristic loss spectrum of polycrystalline tungsten foil measured with 110 eV incident electrons and with a total electron scattering angle of 20°. The ordinate scale is the number of counts accumulated per channel and the abscissa represents energy loss corresponding to a particular channel number. The peak of elastically scattered electrons (open circles) has been plotted on an ordinate scale increased by a factor of 100.

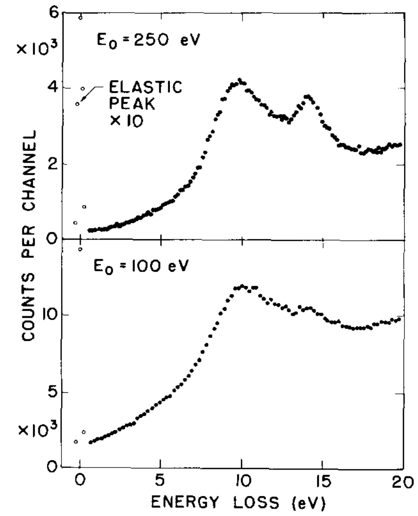

FIG. 3. Characteristic loss spectra of liquid aluminum measured with incident electron energies of 250 eV (top) and 100 eV (bottom) and with a total electron scattering angle of 80°. The peak of elastically scattered electrons (open circles) has been plotted on an ordinate scale increased by a factor of 10.

Figure 3 shows energy loss spectra of liquid aluminum measured with 100 and 250 eV electrons from the monochromator and with a total scattering angle of 80°. These measurements were made with a molten aluminum drop supported on a graphite post heated by electron bombardment.[10] The loss spectra show strong surface and volume plasmon loss peaks at about 9.9 and 14.3 eV, respectively, as determined earlier from scattering experiments with 8 keV electrons.[10] The ratio of the volume plasmon loss intensity to the surface plasmon intensity decreases with decreasing incident electron energy, as expected.[11]

Other results of measurements made with the present system have been published elsewhere.[2]

ACKNOWLEDGMENTS

The author is deeply indebted to Dr. J. A. Simpson and Dr. C. E. Kuyatt for their design of the high resolution electron scattering system used in this program. He also wishes to thank Dr. A. Mandl for his collaboration in acquiring the data shown in Figs. 2 and 3.

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*Work carried out at the National Bureau of Standards under the sponsorship of the U.S. Atomic Energy Commission, Division of Biomedical and Environmental Research.

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