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DESIGN AND CONSTRUCTION OF A HIGH STABILITY, LOW
NOISE, POWER SUPPLY FOR USE WITH HIGH RESOLUTION
ELECTRON ENERGY LOSS SPECTROMETERS

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Abstract

The design and construction of a high stability, low noise, power supply which provides potentials for the lens and analyzer elements of a 127° Ehrhardt-type high resolution electron energy loss spectrometer (HREELS) is described. The supply incorporates a filament emission-control circuit and facilities for measuring electron beam current at each spectrometer element, thus facilitating optimal tuning of the spectrometer. Spectra obtained using this supply are shown to have a 4-fold improvement in signal-to-noise ratio and a higher resolution of the vibrational loss features when compared with spectra taken using a previously existing supply based on passive potential divider networks.

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Introduction

We report here on the design and construction of a high stability, low noise, solid-state power supply for 127° Ehrhardt-type [1] high resolution electron energy loss spectrometers (HREELS). General purpose operational amplifier-based power supplies are used to provide potentials for the 22 lens elements of the spectrometer. Many of these potentials are split to provide deflecting voltages for paired lens elements of the spectrometer. The use of ultrastable, low noise difference amplifiers provide the facility to sweep all of the analyzer voltages rapidly so one may obtain repetitively scanned spectra quickly. Incorporated in this supply is a filament emission control circuit. Included along with a discussion of the design philosophy is a description of the supply electrical specifications and how they are obtained. Examples of spectra obtained using this supply are presented and compared with spectra obtained with the commonly used potential supply based on passive potential divider networks. Substantial improvements in both signal-to-noise ratio and time of data acquisition are observed.

Technique Description

HREELS is used increasingly for detecting the normal vibrational modes of molecules adsorbed on single crystal surfaces under ultrahigh vacuum conditions. The technique was first implemented by Propst and Piper [2] in 1967 and has subsequently been refined mainly through the efforts of Ibach and coworkers [3] at Julich. Today there are many operational spectrometers at laboratories around the world with many more under construction. Most HREELS spectrometers, including those in our laboratory, are of the 127° cylinder type, although successful systems have been built based on cylindrical mirror analyzers [4],

or hemispherical analyzers [5]. When compared with optical techniques, HREELS has the advantage of a wide accessible spectral range, with vibrational losses in the range $\sim 100 \text{ cm}^{-1}$ to greater than $\sim 3500 \text{ cm}^{-1}$ being detectable, and also a high sensitivity, approaching 0.1% of a monolayer for adsorbate species with large dynamic dipole moments. These factors combine to make HREELS an excellent technique for studying the bonding, structure, and surface dynamics of small molecules adsorbed on solid surfaces whether they are in an ordered or disordered state. However, at present, the ultimate resolution of HREELS is rather low ($\sim 50 \text{ cm}^{-1}$ or 6 meV) which leads to interpretational difficulties when applying the technique to study larger molecules with more complex vibrational spectra. A schematic of one of the HREELS apparatuses used in our laboratory is presented in Figure 1. Electrons emitted from a tungsten hairpin filament are monochromatized and focussed onto the crystal specimen by means of the 127° monochromator sector. Electron impact energy is variable between 1-10 eV and the angle of incidence is usually set at 70° with respect to the surface normal. Scattered electrons, some of which have exchanged vibrational quanta with the adsorbate species, are energy analyzed (typically in the specular direction) in the second 127° analyzer sector and detected with a channeltron electron multiplier. Pulses from the channeltron are amplified, shaped and discriminated, and presently are converted to an analogue output with a ratemeter. Spectra are scanned in a constant resolution mode by applying a linear retarding potential (V_g) to the analyzer section of the spectrometer and recorded directly by a chart recorder driven by V_g along the Y axis. As mentioned above, potentials for the elements of the spectrometer were previously generated using a passive resistor network. Noise was reduced to what was considered an adequate level by filtering the output voltages with long time constant (up to several seconds), resistor-capacitor circuits. The scanning voltage, V_g , was

generated using a motor driven potentiometer. Performance figures for both this supply and the newly designed power supply are presented in Table 1.

Design Philosophy and Description

The new HREELS supply we have designed consists of approximately 22 separate lens power supplies. All of the potentials supplied to the monochromator section of the spectrometer must float with respect to the monochromator reference, while the potentials supplied to the analyzer elements must float with respect to the analyzer reference, which itself floats on the monochromator reference. Many of these 22 lens supplies are used as references for the further supplies which generate potentials for pairs of split deflection lenses; we call these delta supplies.

If the expected energy resolution of the HREELS analyzer is on the order of 6 meV and one desires to resolve a peak into at least 10 separate energy bins, the lens supply system must have less than 0.6 mV of peak-to-peak ripple and noise. Additionally, during the time of acquiring a series of spectra the peak drift in any voltage must be less than 0.1 mV. Lastly, the response and settling time of the energy sweep supplies must be fast enough to allow for rapid data-acquisition by means of repetitive scans.

As may be seen from the measured performance figures shown in Table 1, all of the above criterion have been met or exceeded with our new HREELS power supply. Assembly and interconnection of the requisite number of supplies has been facilitated by the design and construction of several general purpose printed circuit cards which have sufficient flexibility and the required speed, stability, and noise characteristics to meet the specifications set forth above.

Figure 2 is a block diagram of a typical lens and delta supply. These general purpose modules are configured for a particular lens by choosing the

appropriate sign of reference supply and selecting the necessary scaling resistors so as to provide the required voltage range for the lens in question.

To achieve good temperature and long term drift stability, we have used a single, temperature stable, voltage reference source. The 10 volt reference supply is a monolithic, integrated circuit device which is available with similar specifications from several manufacturers. The device we used (6) has an offset voltage temperature drift of less than 50 microvolts/ $^{\circ}$ C and less than 80 microvolts/month drift. Since no voltage greater than 55 volts is required for any lens, all of the required reference voltages may be developed from a single 10 volt source by means of stable amplifiers with no more than a factor of 5.5 gain.

Two kinds of operational amplifiers are used. An extremely stable, monolithic, FET input, operational amplifier is used for all of the lenses but two that require a voltage greater than 18 volts with respect to the supply common. The amplifier we selected (7) has a change in offset voltage of less than 0.5 microvolts/degree C and less than 2 micro-volts/month offset drift. For the two lenses that require larger voltage ranges, we use a high voltage FET input, operational amplifier (8), with 25 microvolts/ $^{\circ}$ C offset voltage temperature drift and less than 50 microvolts/month offset drift. The unity gain bandwidth of both amplifiers is greater than 0.6 MHz and the full power bandwidth is greater than 30 kHz. Therefore, a 10 to 90% step response rise-time of less than 0.5 milliseconds for any lens supply is readily achieved along with excellent stability and very little peak-to-peak ripple and noise (see Table 1).

A typical lens supply (Figure 2) consists of these very stable amplifiers connected as shown to function as a difference amplifier. By means of a front panel control potentiometer, the lens voltage may be set to any value in the range allowed for that lens supply. The reference voltage supplied to the

positive input of the difference amplifier will cause the output voltage of the difference amplifier to float in proportion to the reference voltage. Of course, one must initially set up the gains, offset, and common mode rejection for each lens supply. This tedious and painstaking procedure was accomplished upon the initial set up and test of the HREELS supply system and after several months of operation we have not found it necessary to recalibrate or redo any of these adjustments.

The delta supply voltages for the split lens are obtained by floating two temperature stable 10 volt reference supplies upon the lens voltage. This provides a split lens voltage of up to ± 10 volts. The delta supply voltage has much greater stability than that of the lens voltage it is referenced to. The raw supply voltages for the floating reference supply are provided by a commercially available DC-to-DC converter. The converter (9) used in this application is selected for the excellent shielding of the electrical noise from the internal R.F. oscillator. As shown in Figure 2, the range of the delta supply voltages is determined by a low impedance divider string which uses temperature stable metal film resistors and a front panel, 22 turn, cermet potentiometer.

The externally generated sweep voltage is added to each of the analyzer potentials via a buffer amplifier (Figure 2). The magnitude of the sweep voltage for each lens may be set individually by means of a slope control. This feature is provided by changing the input gain determining resistor for each summing amplifier to allow for optimization of the energy resolution of the HREELS spectrometer throughout the spectral range.

Convenient access for adjustment and a means of measuring all lens potentials is provided on the front panel of the HREELS supply (Figure 3). Additionally, the front panel provides a diagram of the electrical interrelation of each supply to the reference potentials and a label indicating the sign and range of

each lens voltage with respect to its reference level. On the front panel all test points and controls are connected by colored traces; unfortunately, the black and white reproduction does not fully show how useful and attractive the red and blue traces on the white background are in the use and set-up of a HREELS experiment.

The front panel has another feature which permits the user to disconnect any lens element from its voltage supply by means of a rocker switch. These clearly labeled switches and the extra test points connected to the lens in question may be seen on the bottom of Figure 3. This has proved very useful in measuring the emission current collected by any lens element. The front panel switches are used extensively in tuning the HREELS monochromator and in measuring the crystal current.

A novel feature of this HREELS supply is the emission stabilization circuit. This provides the user with the ability to set any desired emission current by means of the potentiometer on the HREELS supply front panel. A block diagram of the emission control and stability circuit is shown in Figure 4. The center of the filament may be set to any voltage as determined by the filament level supply (one of the HREELS supplies described above). The emission current may be monitored by a voltage proportional to the emission current which is available at a front panel test point (Figure 4). The feedback control voltage to the floating filament supply is continuously varied by the emission stabilization circuit to maintain constant emission current despite changes in filament temperature and emission properties with time (see Table 1). Use of this circuit has resulted in accurately reproducible spectra, crystal currents, and count rates. One can set up an HREELS experiment on one day and turn off all of the supplies overnight and upon return the next day find all of the supply voltages, currents, and count rates exactly as they were after but a few minutes

warm-up time.

Spectra Comparison

The improvements due to the new power supply are displayed in figure 5. Shown here are the vibrational spectra of carbon monoxide chemisorbed on Pt(111) at 300K at a saturation coverage; spectrum A is obtained with a passive potential divider network power supply similar to that used on nearly all existing spectrometers while spectrum B is obtained using our new high stability, low noise, power supply. Spectra were chosen to allow maximum comparison of differences due solely to the power supplies while maintaining optimal resolution and definition attainable with each power supply. Hence the elastic beam intensity ($2 \times 10^5 \text{Hz}$), the FWHM of the elastically reflected beam (75cm^{-1}), the pass energies of both the monochromator and the analyzer (0.6eV), and the time constant of the analogue ratemeter (10 seconds) are the same for both spectra. The improved signal-to-noise ratio in spectrum B when using the new power supply is clearly evident. Note the increased resolution of all peaks in spectrum B, especially the improved definition of the peaks at 360 and 1870cm^{-1} . Also note that the signal returns to the baseline between peaks in this spectrum. Equally important is that spectrum B was obtained 2.3 times faster than spectrum A (4000cm^{-1} in less than 26 minutes compared to over 59 minutes with use of the passive resistor network).

These improvements are directly related to the very much greater stability and significantly reduced noise (see Table 1) of our new high stability, low noise, HREELS power supply. Although the FWHM of the elastic beam for both power supplies are very similar, resolution is increased in the inelastic spectrum of the new power supply due to the ability to scan at a faster rate with higher signal-to-noise ratio and much improved stability of the supplied

voltages. Just as important yet not apparent in Figure 5 is the ease in which the new power supply can be tuned for optimal resolution and inelastic signal intensity. The ease of tuning, reproducibility, and stability must also be enhanced by the emission stabilization circuit added to this new power supply. These advances allow improved and increased data output in less time.

Further Improvement Opportunities

The improvements in signal-to-noise and data acquisition time obtainable using the high stability, low noise, power supply has been demonstrated. Additionally, this supply has the necessary noise stability and response characteristics to be used in conjunction with a computer-based digital data-acquisition system; we are currently implementing this improvement. Using a computer-based system, the energy sweep input will be a computer generated stair-step ramp. At each discrete step, corresponding to a specific electron energy loss, pulses from the channeltron will be counted and stored. While the data is being collected, the computer will display a real-time histogram of energy vs. total number of counts $[N(E)]$. The process may be terminated once sufficient S/N is achieved. The stored data may then be digitally processed to compare with previously acquired spectra, to deconvolute features, to subtract background, etc.

Furthermore, there is the possibility of replacing the channeltron with a micro-channelplate array and resistive anode at the focal plane of the spectrometer. Coupled with position sensitive electronics, this arrangement would allow a broad energy range of the HREELS spectrum to be acquired simultaneously, reducing the data acquisition time to a small fraction of that required with a traditional single channel counting system.

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9. Burr-Brown, Model 700, Isolated DC-to-AC Converter.

Figure Captions

- Fig. 1 Schematic diagram of a 127° HREELS spectrometer: The filament and monochromator section are rotatable so that possible angular effects can be studied. The spectrometer assembly is mounted on a 200mm Conflat flange.
- Fig.2 Typical lens and delta supply: The block diagram shows a typical differential amplifier circuit used to produce an ultra-stable, low noise, lens voltage. The delta voltages are developed as shown to float upon the lens voltage.
- Fig.3 Photograph of the HREELS power supply front panel: The interrelation of each supply to the reference potentials and the sign and range of each lens voltage with respect to its reference level is diagramed here. The bottom of the front panel contains test points to measure the emission current collected by any lens element.
- Fig.4 Emission stabilization system: A block diagram of the emission current sensing bridge and difference amplifier circuit is shown. This circuit produces a voltage that is proportional to the emission current. This voltage is available at a front panel test point and is used by the feedback control circuit to stabilize the emission current.
- Fig.5 Comparison of the vibrational spectra of CO chemisorbed on Pt(111) at 300K: Spectrum A is obtained with the passive potential divider network power supply, while spectrum B is obtained with our new high stability, low noise power supply. Note the improved definition, resolution, signal-to-noise ratio, and lessened collection time of spectrum B as compared to spectrum A.

Table 1

Characteristics	Solid-State Supply	Potential Divider Network
Noise*	0.5*mV peak-to-peak	2.0 mV peak-to-peak
Ripple	less than 0.25 mV	4 to 20 mV (60 Hz) varies from lens to lens
Time constant	0.003*seconds	up to 20 seconds
Drift/hour period	0.003 mV	50 mV
Time to stablize after start-up	100 seconds	several hours
Emission-stabilized filament supply	Less than ± 0.1 mA change in 24 hours at 21 mA emission current.	This feature is not avail- able in this supply.

* The output noise may be further reduced by limiting the speed of response. See the section on design philosophy for a discussion concerning the design of output characteristics.

Figure 1

XBL 806-5322

DEFINITIONS:
 BA = BUFFER AMPLIFIER
 DA = DIFFERENCE AMPLIFIER
 DC/DC = ISOLATED DC/DC CONVERTER
 F.P. = FRONT PANEL POTENTIOMETER
 SA = SUMMING AMPLIFIER
 VR = ULTRA STABLE 10 VOLT REFERENCE

TYPICAL LENS AND DELTA SUPPLY

Figure 2

XBL 818-11494

Figure 3

CBB 817-6812

DEFINITIONS:

- DA = DIFFERENCE AMPLIFIER
- E = CONTROL PLUS STABILIZATION
- F.P. = FRONT PANEL POTENTIOMETER
- FLS = FILAMENT LEVEL SUPPLY
- FS = FLOATING FILAMENT SUPPLY
- PCA = PHOTO-COUPLED ISOLATION AMPLIFIER
- R = EMISSION CURRENT BRIDGE RESISTOR
- SA = SUMMING AMPLIFIER

Figure 4

EMISSION STABILIZATION SYSTEM

XBL 818-11495

CO ON Pt (111) AT 300 K

Figure 5

XBL8111-6957

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