# An apparatus for determining the secondary electron emission properties of nonconductors

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**Abstract** The apparatus described allows the measurement of the secondary emission coefficient and the secondary electron energy distribution from nonconducting surfaces. The potential of the nonconducting surface is stabilized by a cathode very close to it. The use of an oscillatory primary beam allows a measurement of the secondary emission coefficient. The application of a sinusoidally modulated voltage sawtooth allows the determination of the emitted electron energy distribution and measures the potential of the emitting surface. The performance of the apparatus is demonstrated by results obtained from an amorphous magnesium oxide coating.

## 1 Introduction

The measurement of the secondary emission coefficient from nonconducting surfaces requires that the surface potential be held constant at a known level during the period which is required for the determination. This requirement has been satisfied, generally, by two different methods in other measurements: either by the use of a pulsed primary beam which only causes small surface potential changes interspersed with a discharging process (Bruining 1954, Whetton and Naponsky 1957, Johnson and McKay 1953) or by the use of two electron beams of different energies (Handel *et al.* 1966). The process which is described here essentially employs the latter method of stabilizing the surface except that a beam as such is not used. Further, a geometry has been chosen which allows an emitted electron energy distribution to be obtained. The method, which is applicable to any nonconducting surface, has been used for exploring the properties of amorphous magnesium oxide coatings which might be useful in image converters.

## 2 Apparatus

Figure 1 shows the general arrangement of the apparatus. A beam from the electron gun is admitted into the interior of a hemispherical collector through a drift tube which is at the same potential as the last element in the electron gun. Inside the collector is a concentric hemispherical grid which is also at the same potential as the last element in the gun but not directly connected to it. The diameters of the grid and collector are 10 cm and 11 cm respectively. A secondary emitting target is placed at the centre of the hemispheres with its hole coinciding accurately with their centre. For the measurements described, the target consists of a microscope cover slip (with a tapered hole drilled in it) coated with a layer of powdered magnesium oxide. The smallest diameter of the hole in the cover slip is $\frac{1}{2}$ mm.

A non-inductive 0·005 inch diameter thoriated tungsten cathode is placed as close as possible to the specimen surface, as shown in figure 1, the upper wire being about $\frac{1}{2}$ mm from the surface. The whole apparatus is contained in a glass envelope sealed to a lower metal surface with a grease-free Viton O-ring and continuously pumped to a normal operating pressure of 0·2–0·3 $\mu$torr. The vacuum is provided by a sorption and ion pump system and the apparatus is magnetically and electrostatically screened.

The circuit diagram is shown in figure 2. The circuit on the right-hand side is used to measure the secondary emission coefficient and that on the left hand to measure the electron energy distribution. Considering the latter circuit only, as the increments of the current which are received during the energy distribution measurement are small ($\sim$1 nA) capacitive effects in the measuring circuit are important. These effects are cancelled by using a balanced measuring system with a compensating capacity C. This method is not as sensitive as

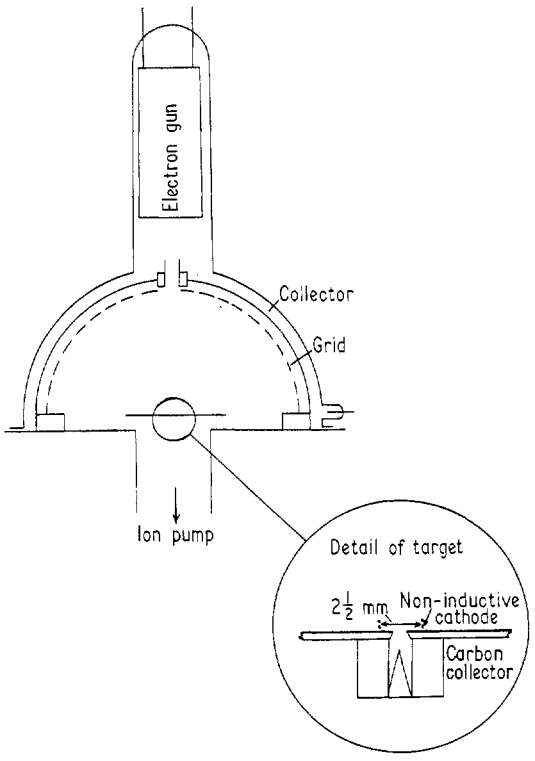


**Figure 1** Diagram of the apparatus

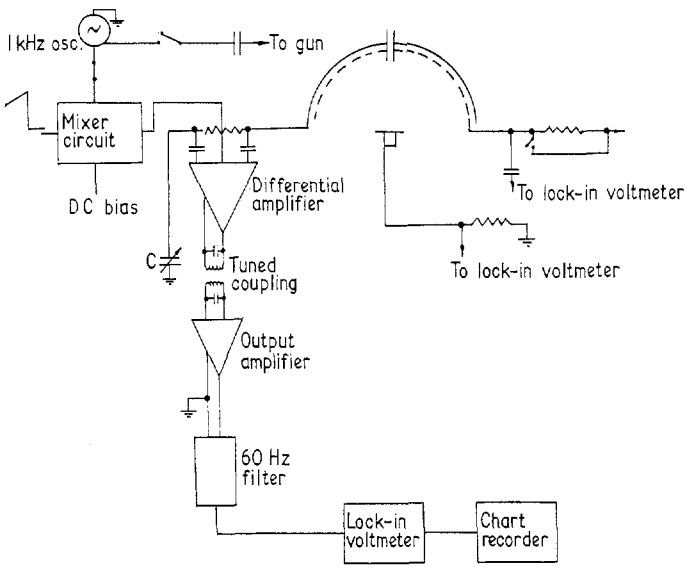


**Figure 2** Circuit diagram

that used by other workers (Nathan and Mee 1967) but is sufficiently so for the signal current available in this apparatus. In order to restrict the bandwidth of the system and to return the signal to relative earth potential a tuned transformer is used between the output amplifier and the preceding stage. The 60 Hz twin-T filter is required prior to the lock-in voltmeter to prevent saturation of its amplifier by mains hum when the maximum gain is used.

### 3 Procedure

Initially an arrangement with three concentric copper rings was placed in the position of the target. The smallest of these rings was $\frac{1}{2}$ mm in diameter, the next, separated by a $\frac{1}{4}$ mm from this, $1\frac{1}{2}$ mm outside diameter, followed by a larger one again spaced by $\frac{1}{4}$ mm. This target was used for two purposes. First, the focusing conditions of the primary beam were checked, and it was found that the spot size produced was better than $1\frac{1}{2}$ mm in diameter. Second, the lower cathode was switched on (together with the bias potential on the hemispherical grid) and the diode curves plotted for the two inner rings of the target. In this way, the satisfactory performance of the lower cathode was demonstrated. It was shown that for the region in which the apparatus could be expected to work, the final specimen surface would be of the order of 20–30 V positive with respect to the cathode. A check was then made, using an electrostatic model, that secondaries from the target could reach the grid and collector from a relatively large solid angle. At this point, it became obvious that an unjustifiably large potential could exist over the target area and that it might be possible for the beam to be inaccurately centred. As a consequence the target design included the $\frac{1}{2}$ mm hole backed by a non-emitting carbon collector. Approximate calculation showed that less than $\frac{1}{2}$ V potential difference could be expected over the target area which was receiving the primary electron beam (even in the absence of the stabilizing effect due to the transport of secondaries across the surface) provided the incident beam was of the order of 1 $\mu$A. Further, if the electron density distribution in the primary beam is of the form

$$n_r = AJ_0(2{\cdot}405\, r/r_0) \tag{1}$$

(with $r_0 = 0{\cdot}75$ mm) then the presence of this $\frac{1}{2}$ V potential difference would be small in its effect on the observed energy distribution. The choice of the relatively large radii of the grid and collector was made so that distortion of the energy distributions through the relationship

$$\frac{\Delta E}{E} = \left(\frac{a}{b}\right)^2 \tag{2}$$

(where $a$ and $b$ are the effective radii of the emitting and collecting surfaces) would be very small indeed. This topic is discussed in detail by Lukirsky (1924) and Nathan (1967 PhD Thesis University of Southampton).

It is convenient to measure the secondary emission coefficient before determining the energy distribution. This is effected by focusing the modulated (1000 Hz) primary beam on to the target and measuring the current received by the carbon collector with the lower cathode isolated and unheated. At this stage the primary beam intensity is adjusted. The grid is maintained at +300 V with respect to earth and the hemispherical collector grounded; thus the net modulated secondary emitted current $i_0$, which is equal to the beam current falling on the magnesium oxide surface, is measured at the grid. The lower cathode is switched on, earthed and its temperature raised until the total modulated secondary emission current $i_s$ received at the grid shows saturation. Equation (3) determines the secondary emission coefficient:

$$\delta = i_s/i_0. \tag{3}$$

The results for the powdered magnesium oxide coating are shown in figure 3.

The electron energy distribution is determined by applying a 1000 Hz modulated sawtooth to the hemispherical collector with a dc primary beam bombarding the target. Only the

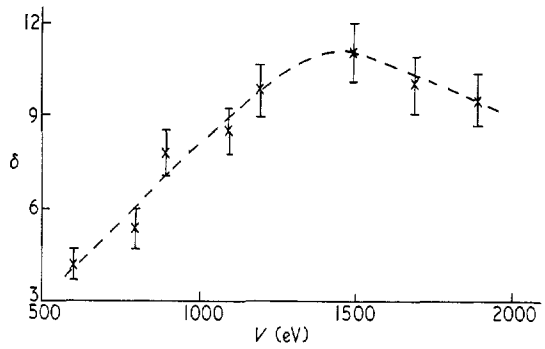


**Figure 3** Secondary emission coefficient for amorphous magnesium oxide

current component at the 1000 Hz modulation is measured in the lock-in voltmeter. The energy resolution achieved in these measurements depends, among other factors, on the rate of rise of the sawtooth relative to the amplitude and frequency, of the modulation as well as the integrating time of the lock-in voltmeter (Nathan 1967 PhD Thesis, University of Southampton). Explicitly, if the current recorded at the collector due to the secondary emission can be written as

$$I = f(V) \tag{4}$$

then, noting that

$$V = V_0 t/T + V_1 \sin \omega t \tag{5}$$

it follows that

$$\mathrm{d}I/\mathrm{d}t = f'(V)\,(V_0/T + \omega V_1 \cos \omega t) \tag{6}$$

i.e.

$$\mathrm{d}I/\mathrm{d}t \simeq f'(V)\,(\omega V_1 \cos \omega t) \quad \text{as} \quad V_0/T \ll \omega V_1.$$

If a time $\tau$ is chosen, so that $\tau \ll T$, for the integrating time of the lock-in voltmeter (which only extracts a component

corresponding to cos $\omega t$), then at any instant of time we have

$$i_V = \left(\frac{dI}{dt}\right)_V = kf'(V). \qquad (6a)$$

Thus, a plot of $i_V$ against $V_0 t/T$ gives a curve directly proportional to that of the energy distribution. For the data presented (figure 4) the rate of rise of voltage (sawtooth) was about 1/5 V $s^{-1}$, the modulation voltage 300 mV peak to peak and the integration time 300 ms. Some indication of the resolving

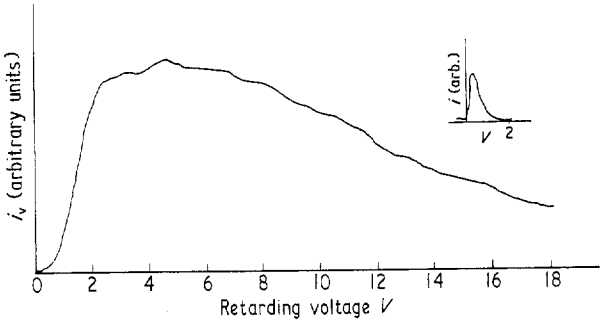


**Figure 4** Typical electron energy distribution curve. Inset: thermionic emission from lower cathode

power of the system can be obtained from the measurement of the energy distribution of the thermionic emission from the lower cathode and the plot is shown in figure 4 (which is, of course, referred to a different zero potential than that of the secondary emission curve). The potential, relative to earth, of the emitting surface is found from the position of the cut-off in the energy distribution curve, i.e. the highest sawtooth voltage at which a non-zero signal is received. In the plot shown this was 27 V.

## 4 Conclusion

The apparatus which is described is conveniently capable of reasonably accurate measurement of the energy distribution of secondary emitted electrons. The final limit of its resolving power is, in practice, determined by the small potential difference over the surface which is being bombarded. This can be improved by using a more sharply focused beam, provided that the surface potential is sufficiently raised (to exclude the thermionic emission of the lower cathode from the plot) and also provided that the energy input into the specimen is limited so that it does not cause unwanted effects.

The apparatus is no more accurate for the measurement of the secondary emission coefficient than its predecessors.

**Acknowledgments**

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