IMPEDANCE METER FOR SEMICONDUCTOR SURFACE CAPACITY MEASUREMENTS

By

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Introduction

A useful method of investigating chemical changes, such as chemisorption, at semiconductor-electrolyte interfaces is to measure the space-charge capacity. The space-charge capacity of a semiconductor is a function of the surface-charge capacity, which is subject to changes in the charge transition processes taking place on the surface.

Space-charge capacity is measured at frequencies above 10^4 Hz [1, 2], because the part of the circuit at the interface can then be thought of as being replaced by a simple electric unit consisting of a condensor and a resistor connected in series, which makes the space-charge capacity easy to determine. In many interface studies it is also necessary to obtain a measure of the frequency-dependence of the space-charge capacity. It is an important requirement for any instrument used for such purposes that the tested semiconductor electrode can be put earth. Besides for the sake of determining the capacity at the required accuracy impedances with phase angle less than 45° should be measured precisely. Only signals of low (several millivolts) amplitude can be used for the measurements, else the polarization conditions at the interface (determined by the polarization voltage applied during the measurement) will be considerably affected. Lastly, in order to make the time dependence of the capacity under given conditions accessible to study it to carry out many measurements in a short time, the measurement process itself must be fast and easy to perform.

As the common measuring devices do not meet all the above requirements we have designed and built a "Z-meter" free from this deficiency. This paper reports on the meter's principle of operation and its accuracy. The measuring conditions and our own studies on phenomena at semiconductor-electrolyte interfaces will be discussed in subsequent publications.

Principle of operation

The instrument works as follows (see Fig. 1): Impedance Z_m to be measured is connected to the output terminals of generator G across the variable standard resistance R_H and dropping resistors R_0. C and R_p as well as the two identical resistors R are both connected in series in the same manner.

A phase indicator is connected to points AB or BC. A vector diagram of the signals obtained is shown in Fig. 2. The capacitance of C is chosen so that its impedance is equal to R_p at the measuring frequency, i.e. the voltage vector U_{CB} is exactly perpendicular to measuring signal U_{DE}. If R_H is adjusted so that the phase angle between U_{AC} and U_{CB} is zero, U_{RH} and U_Z will be equal, hence $Z = R_H$. If the input terminals of the phase indicator are connected between AE and CF, the position of the slider on R_p can be adjusted so that U_{AE} and U_{CF} will be parallel, hence their phase angle will likewise be zero. The potentiometer scale can therefore be directly calibrated in φ-values giving a direct reading of the phase angle.

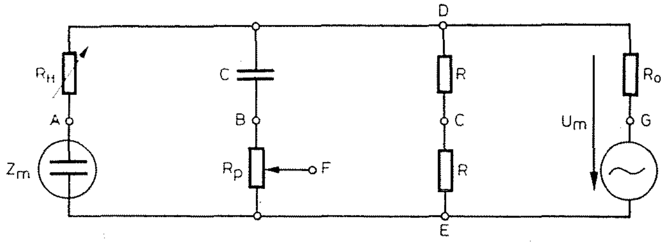

Fig. 1

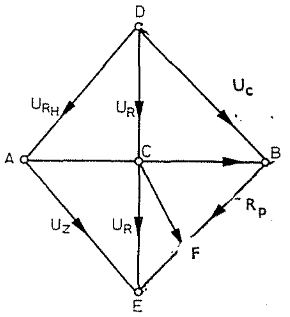

Fig. 2

Construction of the apparatus

The phase indicator is an oscilloscope tube; the signals to the horizontal and vertical deflecting plates are provided by selective amplifiers with differential inputs. These inputs are connected to points AB and CB when measuring Z and to points AE and CF when measuring φ. The gain of the selective amplifiers is high enough to permit the full modulation of the electron beam on the screen even with an input signal of 1 mV. An ellipse is seen on the screen if the circuits are unbalanced on either side. The equilibrium is found by varying R_H or R_p until the ellipse is closed to a 45° straight line.

As can be seen from the vector diagram, balancing begins with the determination of Z. There is, however, no need to correct R_H during the measurement, eliminating the lengthy iterated process of minimization proper to conventional measuring bridges. Moreover the iteration cannot become divergent and thus Z and φ are determinable, even for small phase angles. Another advantage over the conventional Z-meters (Grützmacher bridges) is that one of the electrodes of the measuring cell can be permanently earthed, thus, shielding is easier and even a 20 to 30 MHz measuring frequency can be obtained by using a low-capacity R_H and R_p.

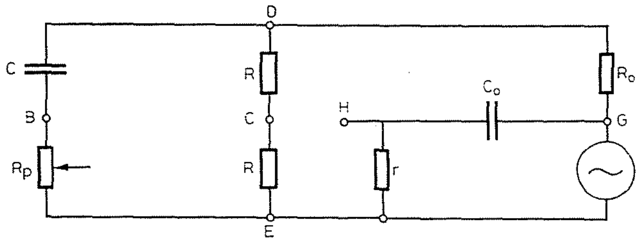

Fig. 3

To change the measuring frequency, the frequencies of the measuring-signal generator and both selective amplifiers as well as the value of C must be changed simultaneously. As our measuring generator covers the 160 Hz to 320 kHz frequency range in 11 steps, a great number of elements must run exactly together, since the phase transmission of both selective amplifiers must be identical. Hence the following calibrating stages are involved in tuning the above units: 1. All the selective amplifier inputs are connected to points CE, i.e. in each position the built-in tuning capacitors must be regulated until the ellipse on the oscilloscope screen closes, indicating identical phase transmission; 2. X_C (reactance of capacitor C) and R_p are balanced by connecting the inputs of one of the selective amplifiers across points BC. With a zero voltage at one input of the other amplifier, a signal shifted by 90° compared to the measuring signal is applied to the other one from a series-connected potential divider consisting of a capacitor C_0 and resistor r. The circuit and its vector diagram are shown in Figs 3 and 4, resp. When X_{C0} is by two orders of magnitude greater than r, U_r is perpendicular to the measuring voltage vector U_{DE} at an error of a few tenths of a degree sufficiently accurate adjustment can be made at all frequencies.

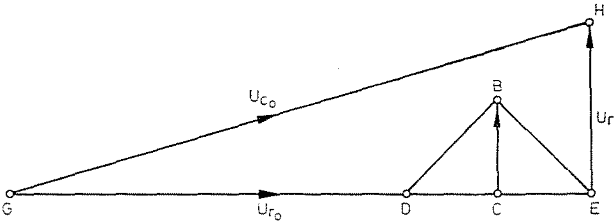

Fig. 4

The equipment also contains a high output resistance current generator supplying the polarization current for the electrodes, a voltmeter and a pH meter. These units are wired in the conventional way. Main technical specification of the equipment:

Measuring frequency	160 Hz to 320 kHz
Measuring signal amplitude	1 mV to 50 mV_{eff}
Range of impedance measurement	10 Ω to 1 MΩ
Error of impedance measurement	max. ±2%
Range of phase angle measurement	0 to 90°
Error in phase angle measurement	max. ±2%
Polarization currents	2 μA to 2 mA
Polarization voltage measurement between	±2 V; ±2%.

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Summary

A non-iterative, compensated, impedance-phase angle meter with an oscilloscope phase indicator has been designed and built for measurements of space-charge capacity at semiconductor (germanium)-electrolyte boundaries. The instrument can operate over a wide measuring range (160 Hz to 320 kHz). Maximum amplitude of the measuring signal is 10 mV. Measuring error for both Z and φ is max. ±2%.

References

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