United States Patent

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[54] RETARDING FIELD ELECTRON DIFFRACTION SPECTROMETER HAVING IMPROVED RESOLUTION

4 Claims, 7 Drawing Figs.

[52] U.S. Cl. 250/49.5
[51] Int. Cl. H01j 37/26
[50] Field of Search 250/49.5 1, 49.5 8

[56] **References Cited**

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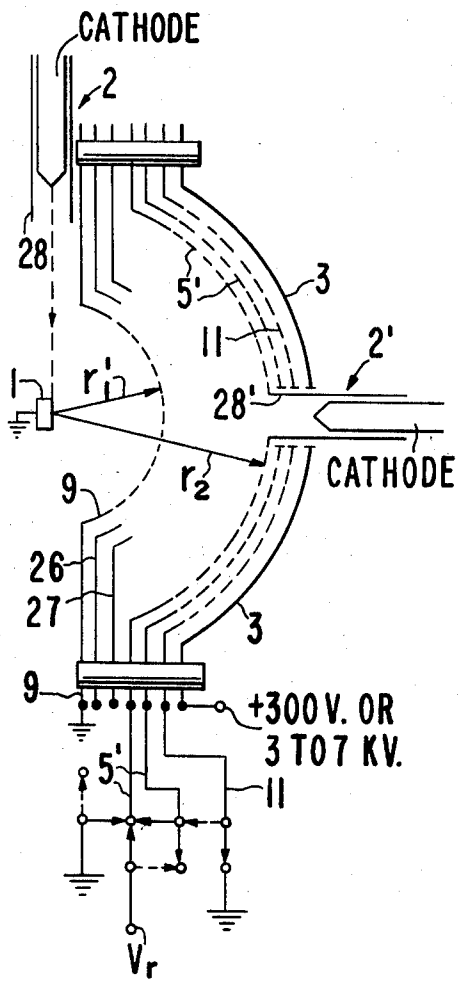
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" Double Grid Repeller System to Improve Electron Resolution in Low Energy Electron Diffraction Equipment" by C. W. Caldwell, Jr. from " The Review of Scientific Instruments", Vol. 36, No. 10, Oct., 1965, pages 1500 & 1501

Primary Examiner—William F. Lindquist
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ABSTRACT: A retarded field electron diffraction spectrometer is disclosed which includes an electron gun for directing substantially monoenergetic electrons onto the surface to be examined of a target to produce scattered electrons from such surface. A spherical retarding grid structure is concentrically disposed of the target in the space between the target electrode and a concentric spherical fluorescent screen. A retarding potential applied to the retarding grid permits only those target scattered electrons having a potential greater than the potential of the retarding electrode to reach the fluorescent screen. The retarding grid electrode has grid openings defining electron passageways having a characteristic diameter less than three times the characteristic length thereof to improve the uniformity of the retarding field. A spherical shield grid electrode is concentrically disposed of and has a radius within the range of 0.3 to 0.8 of that of the retarding grid to enhance the resolution of the spectrometer.



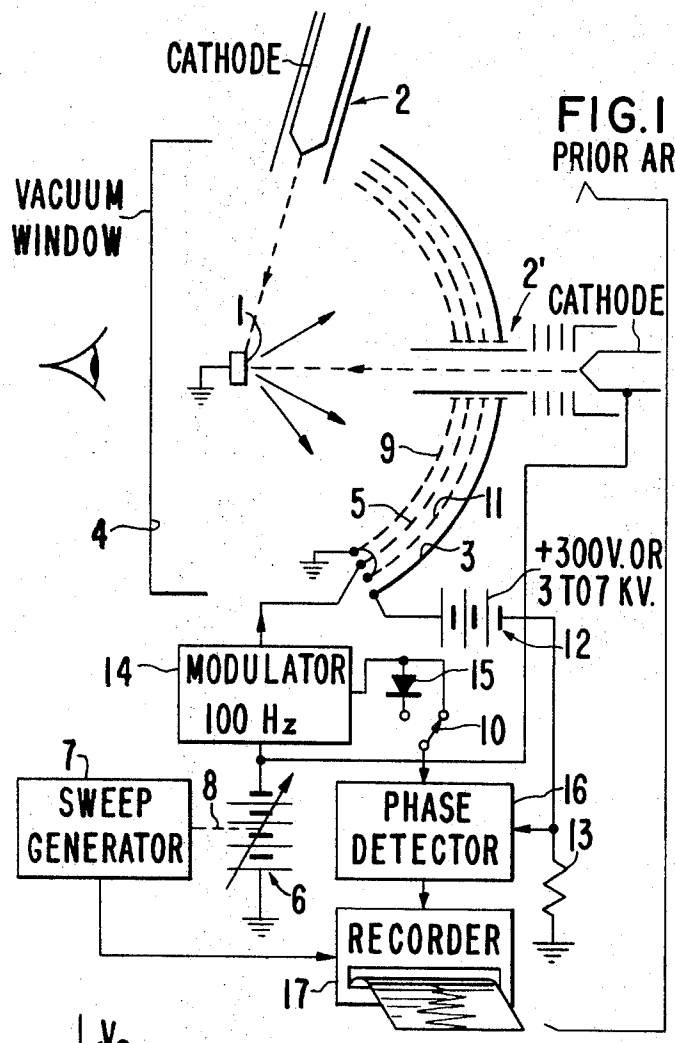


FIG. 1
PRIOR ART

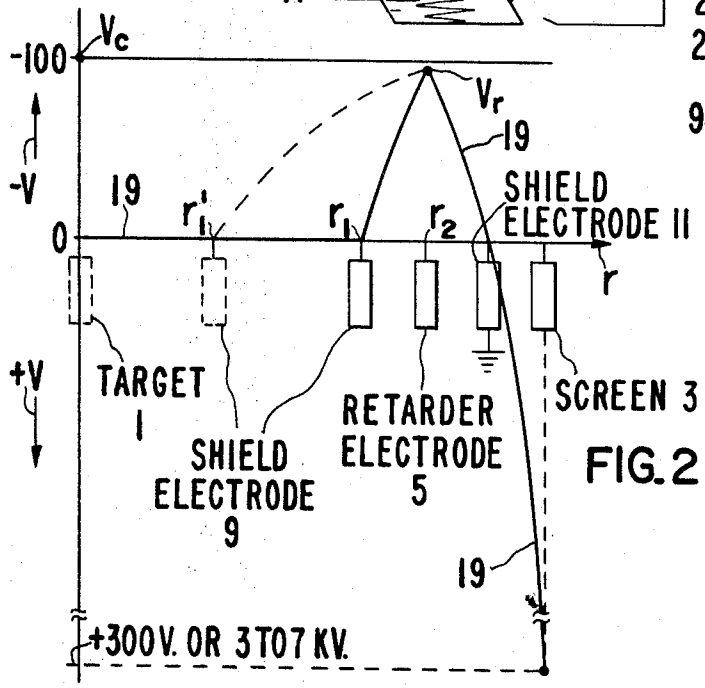


FIG. 2

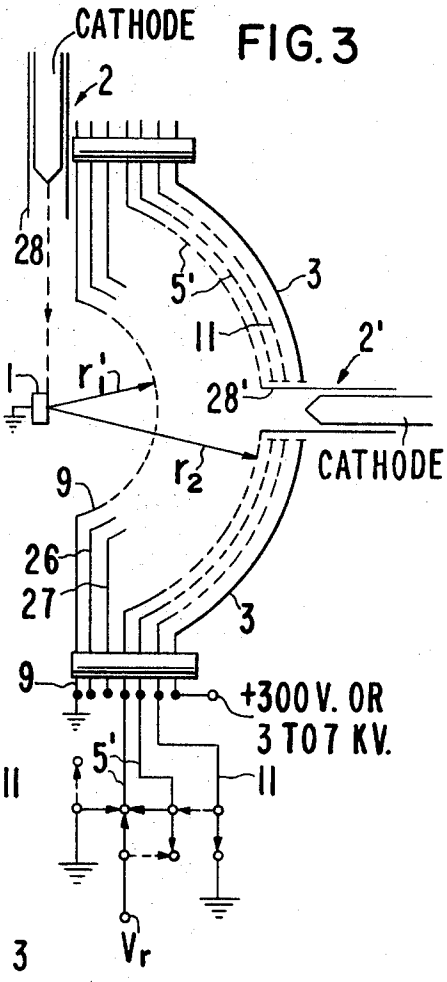


FIG. 3

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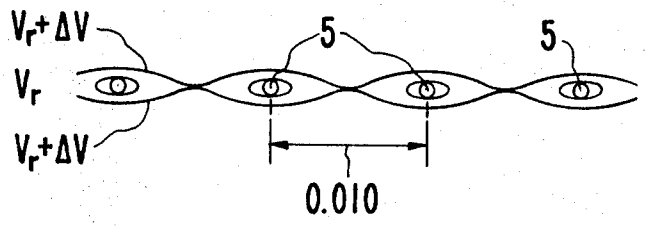


FIG.4

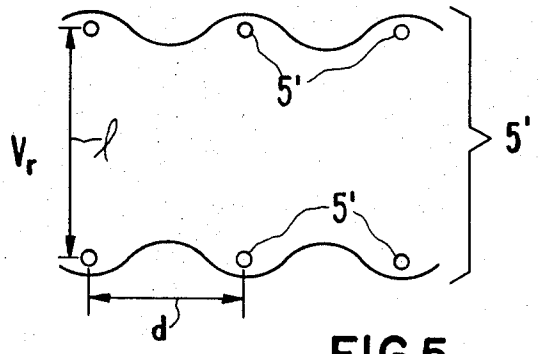


FIG.5

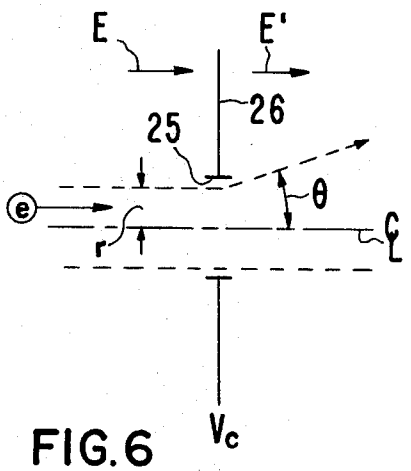
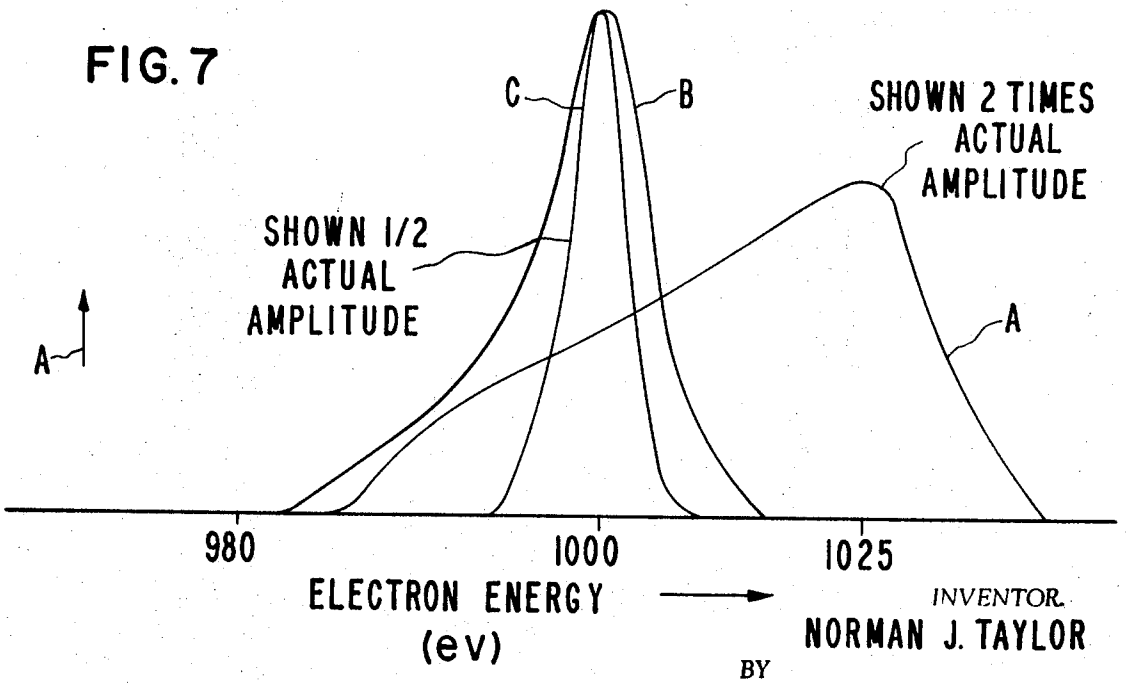


FIG.6

FIG.7



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RETARDING FIELD ELECTRON DIFFRACTION SPECTROMETER HAVING IMPROVED RESOLUTION

DESCRIPTION OF THE PRIOR ART

Heretofore, retarding field electron diffraction devices have been built. One such device is described in U.S. Pat. No. 3,313,936 issued Apr. 11, 1967 and assigned to the same assignee as the present invention. Other similar devices operated as spectrometers are described in the Journal of Applied Physics, Vol. 39, No. 5 of Apr. 1968, pages 2,425 to 2,432 and in the Journal of Applied Physics, Vol. 38, No. 8 of July 1967, pages 3,320 to 3,322.

Briefly, the prior spectrometers include a target electrode structure typically operated at ground potential and having a surface such as a certain crystallographic plane which it is desired to examine to determine the surface characteristics thereof. An electron gun structure is provided for directing a stream of substantially monoenergetic electrons onto the surface of the target electrode to produce scattered electrons. A spherical fluorescent screen is concentrically disposed around the target electrode for collecting certain ones of the scattered electrons to form an optical diffraction pattern on the screen. The electron current collected by the screen electrode is also measured as a function of the scanned electron beam potential to obtain an energy distribution of the scattered electrons.

A spherical retarding grid structure is interposed between the target and the screen to prevent scattered electrons having less potential energy than a certain predetermined potential from reaching the screen. In this manner, inelastically scattered electrons may be separated from elastically scattered electrons. It has also been observed that if the electron beam is directed onto the target surface to be analyzed at a glancing angle of incidence that the scattered electrons to be observed originate closer to the surface and therefore contain more information about the surface.

In these prior spectrometers the retarding field grid electrode structures are typically interposed between two shield grid electrodes which are relatively closely spaced to the retarding field grid. With this arrangement it has been common to obtain energy resolutions in the electron energy distribution of approximately 2.4 percent where resolution is defined as the full width at half the maximum amplitude in electron volts, of the electron peak under observation divided by the electron volts at the center of the peak. While a resolution of 2.4 percent is relatively good, it is desirable to increase the resolution by approximately a factor of 10 such that surface effects and characteristics can be more readily discerned.

SUMMARY OF THE PRESENT INVENTION

The principal object of the present invention is the provision of a retarding field electron diffraction spectrometer having improved resolution.

One feature of the present invention is the provision, in an electron diffraction spectrometer, of a retarding field grid structure having openings defining electron passageways therethrough with a characteristic diameter less than three times the characteristic length of the passageways, whereby the retarding field potential is made substantially more uniform across the electron passageways through the retarding grid for enhancing the resolution of the spectrometer.

Another feature of the present invention is the provision, in an electron diffraction spectrometer, of a curved retarding field grid structure surrounding the target electrode with a shield grid structure concentrically disposed between the retarding grid and the target electrode, such shield to be operated at substantially target electrode potential and wherein the shield grid is disposed at a radius falling within the range of 0.3 to 0.8 of the radius of the retarding field grid, whereby the resolution of the spectrometer is substantially improved.

Another feature of the present invention is the same as any one or more of the preceding features wherein the retarding field grid electrode comprises a pair of concentrically

disposed grids with the spacing inbetween the grids being substantially greater than the characteristic diameter of the apertures in the grids.

Another feature of the present invention is the same as any one or more of the preceding features wherein a shield grid electrode structure is provided on opposite sides of the retarding field grid for shielding the retarding field grid from the target and from the fluorescent screen.

Another feature of the present invention is the same as any one or more of the preceding features wherein the electron gun assembly includes an elongated conductive tube for containing the electron gun assembly, such tube being disposed to project radially through aligned apertures in the screen and retarding grid, such tube being directed substantially at the target, and the inner end of the gun tube being terminated substantially at the inner concave surface of the retarding grid whereby the gun tube does not perturb the radial electric field when employing the apparatus for Auger electron spectroscopy.

Other features and advantages of the present invention will become apparent upon a perusal of the following specification taken in connection with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic line diagram, partly in block diagram form, of a retarding field electron diffraction spectrometer of the prior art,

FIG. 2 is a plot of voltage versus radial distance from the target electrode depicting the positions of the various electrodes of the spectrometer and the voltage profile associated therewith,

FIG. 3 is a view similar to that of FIG. 1 depicting a portion of an electron diffraction spectrometer incorporating features of the present invention,

FIG. 4 is a schematic line diagram depicting a portion of the retarding field electrode structure of the prior art and the electrostatic equipotentials associated therewith,

FIG. 5 is a diagram similar to that of FIG. 4 depicting equipotentials associated with an improved retarding field grid structure of the present invention,

FIG. 6 is a schematic drawing depicting the trajectory of an electron passing through an aperture in an electrode having electric fields E and E′ on opposite sides thereof, and

FIG. 7 is a plot of screen current amplitude versus voltage applied to the retarding field electrode and depicting the electron energy distribution obtained from prior art structure versus similar signals obtained using first and second embodiments, respectively, of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1, there is shown the typical prior art retarding field electron diffraction spectrometer. Such a device is described in great detail in the aforecited U.S. Pat. No. 3,313,936. Refinements in the grid structure and electronics which permit it to operate as a spectrometer are described in the aforecited Journal of Applied Physics articles Vol. 38 and 39, respectively. Briefly, the spectrometer includes a target electrode structure 1 which contains the sample of matter to be investigated such as a certain crystallographic plane of a crystalline sample. The target electrode is typically operated at ground potential. An electron gun assembly 2 or 2′ is disposed to project a stream of substantially monoenergetic electrons onto the surface of the target 1 to be investigated. The spectrometer may include one or both of the guns 2 and 2′, respectively.

Gun 2 is provided such that it directs its primary beam of electrons onto the surface of the target to be investigated at substantially glancing angles of incidence relative to the surface to be investigated. In this manner, the primary electrons penetrate the surface to a lesser depth than that penetration obtained by a beam of electrons directed normally to the surface 1 such as that obtained from the other electron gun 2′. As

a result, the electrons scattered from the surface of the target by a beam directed from gun **2** contain more information indicative of the surface.

A spherical fluorescent screen **3** is concentrically disposed of the target **1** to receive the scattered electrons thereon to produce a diffraction pattern on the fluorescent screen **3**. The screen is observable through a vacuum tight window **4** by an observer located outside of the vacuum envelope structure of the spectrometer, not shown. A retarding field grid **5** is concentrically disposed of the target **1** and fluorescent screen **3** in the space between the target **1** and screen **3**. A retarding potential derived from a source of retarding potential **6** is applied to the retarding field grid **5** such that scattered electrons having less potential than that applied to the retarding grid **5** are prevented from reaching the fluorescent screen **3**. By sweeping the retarding field potential, from cathode potential toward the potential of the target electrode **1**, the electron energy spectrum of the scattered electrons is obtained. The sweep for the source **6** is obtained from a sweep generator **7** which varies the output potential of the source **6** via, for example, a suitable mechanical linkage **8**.

A pair of grounded shield grids **9** and **11** straddle the retarding grid **5**. In carrying out electron diffraction using only the elastically scattered electrons, the fluorescent screen is held in the range of +3 kv. to +7 kv. so that the phosphor is well excited for visual observation of the diffraction pattern. In the case of electron spectroscopy, the screen electrode **3** is typically operated at about 300 volts positive with respect to the grounded shield electrode **11** such that the majority of secondary electrons created at the phosphor are returned to the phosphor between the screen **3** and shield electrode **11** and do not enter the retarding field region between grids **11** and **5** where they could be further modulated. The 300 volts also ensures that electrons leaving the target with energies of less than a few electron volts do not give rise to charging problems at the phosphor.

The potential is supplied from a source of potential **12**. A load resistor **13** is connected between the screen **3** and ground such that the current collected by the screen produces an output voltage across the load resistor **13**. The retarding potential as applied to retarding grid **5** is amplitude modulated with a small amplitude relatively low frequency signal, as of 1 volt peak-to-peak amplitude and 100 to 1,000 Hertz, via modulator **14**. A sample of the modulation signal derived from the modulator **14** is fed via switch **10** to one input of a phase sensitive detector **16** to be compared in phase with an output extracted across the load resistor **13**. The output of the phase detector is a DC signal having a phase and amplitude corresponding to the scattered electron energy distribution function. The output of the phase sensitive detector **16** is fed to one input of a recorder **17** and recorded as a function of the sweep signal derived from sweep generator **7** to obtain an energy distribution spectrum of the sample under analysis, as shown by curve A of FIG. **7**.

A more convenient mode of operation of the spectrometer is described in the aforecited Journal of Applied Physics article Vol. 39 of Apr. 1968. In this mode, the detector **16** is tuned to the second harmonic of the modulation frequency obtained from modulator **14**. A diode multiplier **15** is switched via switch **10** into the line between the modulator **14** and the input to phase detector **16** such that the second harmonic of the modulation frequency can be compared with the second harmonic output derived across resistor **13**. This permits the output of the phase detector **16** to comprise the first derivative of the energy distribution which is recorded as a function of the swept beam voltage, as a result, the energy peaks of the energy distribution function are more readily discerned from the background. However, the resolution in the spectra is independent of the mode of operation and the resolution as shown in FIG. **7** can also be achieved when the output is the derivative of these curves.

Referring now to FIG. **2**, there is shown by the solid line **19** the potential profile in the radial direction within the spectrometer of FIG. **1**. In the particular case illustrated, the beam voltage V_c is −100 volts relative to the target electrode. The retarder electrode **5** has a potential of approximately 98 volts and the screen **3** has a positive potential of approximately 300 volts. Electrons scattered from the target **1** with electron volts equal to or exceeding 98 volts pass through the retarding electrode **5** and are accelerated and bombard the fluorescent screen **3** with a minimum energy of approximately 400 electron volts. A typical electron energy profile of an elastic peak is depicted by line A of FIG. **7** and shows a relatively broad energy peak which peaks up at approximately 1,025 electron volts when the primary beam has a beam voltage of 1,000 volts and a current of approximately 15 microamps with the retarding field modulation being approximately 1 volt peak-to-peak amplitude. The resolution of curve A is approximately 2.4 percent and it is desired to substantially improve this resolution.

One of the factors having a deleterious effect upon resolution of the output spectra of the prior art spectrometer of FIG. **1** is that the retarding field grid electrode **5** is relatively open, there being approximately 100 square grid openings per linear inch and the grid wires **5** being approximately 0.001" in diameter, see FIG. **4**. As a result, the equipotential V_r corresponding to the retarding potential applied to the retarding grid **5** bows inwardly of the grid producing a substantial nonuniformity in the retarding potential across the cross section of each of the openings in the retarding grid **5**. This results in relatively poor energy selection by the retarding field electrode structure **5** and constituted a substantial contribution to the relatively poor resolution of only 2.4 percent.

Referring now to FIGS. **3** and **5**, there is shown a retarding grid electrode structure **5'** of the present invention. In the improved grid structure **5'**, two similar grids **5'** are connected together to be operated at the same potential. These grids **5'** are concentrically disposed spherical sections having grid openings of, for example, 100 mesh, the same as used in the prior art grid structure of FIGS. **1** and **4**. The grids **5'** are conveniently spaced apart, in the radial direction by the distance l which is preferably substantially greater than one third the characteristic cross sectional dimension, d, of the openings in the grid **5'**. In a typical example, l is approximately 10 times as great as d. In such a case the more positive equipotential lines penetrate only partially into the composite grid structure **5'** such that in the center of the grid structure the equipotential V_r extends completely throughout the grid to form a uniform potential barrier for rejecting electrons attempting to pass through the grid with energies less than the retarding potential V_r. Although a double mesh type grid structure **5'** has been shown, it is not a requirement that the structure comprise spaced grid members but may comprise a metallic cellular structure such as that formed by the conventional hexagonal grids employed for many years in the reflex microwave tube art. The primary consideration is that the grid structure **5'** should have electron passageways therethrough which have a diameter d less than three times the length l of the electron passageway. Preferably such passageways have a length l several times the dimension d. Also when two grids **5** are employed the holes in the two grids need not be in alignment.

Use of the improved retarding grid structure **5'** results in a substantial enhancement of the resolution of the energy spectrum of the scattered electrons, as shown by curve B of FIG. **7**. However, upon an examination of curve B of FIG. **7**, it is seen that the characteristic resonance line shape is distorted on the low energy side and it is believed this is due to aberrations in the electron trajectories produced as the electrons pass through the first shield grid **9** when such grid is in a position as shown in FIG. **1**, i.e., has a radius of at least 95 percent of the radius of the retarding grid **5**.

Referring now to FIG. **6** it can be shown that electrons passing close to the edge of the aperture **25** in a plate **26** having electric fields E on one side and E' on the other side will suffer large angle deviations θ approximately according to the following expression:

$$\tan\theta=\frac{r}{4}\frac{E'-E}{V_c} \qquad (1)$$

where,

V_c is the electron energy at the aperture **25**,

r is the initial radial distance of an electron trajectory from the axis of the aperture, and

E' and E are the electric fields on opposite sides of the plate **26**.

In the case of the spectrometer of FIGS. **1** and **2**, the electric field E on the target side of grid **9** is 0. Thus, equation (1) reduces to:

$$\tan\theta=\frac{r}{4}\frac{E'}{V_c} \qquad (2)$$

For a finite V_c and a given size opening in the grid **9**, θ can be reduced by reducing E'. In the case of a spherical condenser, the electric field is found to be a minimum when the radius of the inner spherical conductor is just equal to ½ the radius of the outer conductor. Thus, in the structure of FIG. **3** the inner spherical shield grid **9** has been moved to a radius r_1 which is approximately one-half of the radius r_2 of the inside concave surface of the retarding grid structure **5'**. Additional spherical electrodes **26** and **27** are placed at the edges of the spherical grid **9** between grid **9** and the retarding grid structure **5'** to preserve the shape of the equipotentials in the marginal areas of the grid structures **9** and **5'**. Suitable potentials intermediate the ground potential of grid **9** and the retarding potential V_r are applied to electrodes **26** and **27**, respectively, to preserve the spherical shape of the equipotentials in the region between shield grid **9** and the retarding grid structure **5'**. The improvement in resolution obtained by moving the inner shield grid **9** to approximately ½ the radius of the retarding grid structure **5'** is seen by curve C in FIG. **7**. The resolution of curve C is approximately 0.3 percent and represents an enhancement by a factor of approximately 10 in resolution as compared to that resolution represented by the prior art, namely, curve A.

The expression for the electric field intensity at the inner conductor of a spherical condenser is:

$$E_{r_1}=\frac{V_c r_2}{r_1(r_2-r_1)} \qquad (3)$$

where,

r_1 is the radius of the inner grid **9**,

and,

r_2 is the radius of the retarding grid **5'**.

In a typical example, the retarding grid has a radius r_2 of 2.3'' and the inner grid **9** is chosen to have a radius r_1 of approximately 1.5'' (65 percent r_2). Substitution of these values into equation (3) above shows that the electric field E_{r_1} is only 10 percent greater than the minimum value obtained when r_1 is equal to $\frac{1}{2}r_2$. However, this 10percent increase over the minimum still results in an electric field approximately 1/5 that obtained in the prior art when the spacing between the inner grid **9** and the retarding grid **5** was approximately 0.120'' and r_1=96 percent r_2. Thus, it can be seen that the placement of the inner shield grid **9** at precisely the minimum electric field is not critical. However a substantial improvement can be obtained in the resolution of the spectrometer by having the radius of the inner shield grid **9** fall within the range of 30 to 80 percent of the radius of the retarding field grid **5'**.

Referring now to FIG. **3**, there is shown an electron diffraction spectrometer apparatus suitable for observing both elastically and inelastically scattered electrons. More specifically, the obliquely disposed electron gun **2** may be employed for Auger electron studies of the surface of the target **1**. When the spectrometer is employed in this manner for observing the Auger electrons, the gun tube **28'**, which contains the cathode of the normally disposed electron gun assembly **2'**, is preferably terminated at its inner end in the plane of the inner surface of the concave retarding field grid **5'**. In addition, the gun tube **28'** is electrically connected to the retarding grid **5'** to prevent perturbation of the electric field in the region between the shield grid **9** and the retarding grid **5'**.

On the other hand, when the apparatus of FIG. **3** is to be employed for low energy electron diffraction, i.e., for studying electrons elastically scattered from the target **1** the normally disposed electron gun **2'** is employed and the obliquely disposed gun **2** is deenergized. In such a case, the gun tube **28'** is preferably operated at ground potential and, thus, the innermost grid of the double retarding grid structure **5'** is insulated from the outer grid **5'** and connected to the gun tube **28'** and to the inner grid **9** to operate at ground potential. In this manner, the beam suffers no deterioration or deviation in passing from the gun tube **28'** to the sample **1**. In this latter case, however, the outer grid of a retarding grid electrode **5'** is insulated from the inner grid and operated at the retarding field potential V_r. This reduces the resolution somewhat but a resolution of better than 0.5 percent can be obtained by connecting grid **11** to the retarding grid **5'** to form a double grid structure having the same characteristics as double grid **5'**. Since modulating voltages are not applied to grids **5'** in this mode, AC measurements are not made and there is no need for any ground shield between the retarding field grids **5'** and **11** and the screen **3**. A resolution of 0.5 percent at 100 volts corresponds to 0.5 e.v. which is most satisfactory for electron diffraction purposes. The arrangement of FIG. **3** permits a common electrode configuration to be employed for study of both elastically scattered electrons and Auger electrons.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What I claim is:

1. An electron diffraction spectrometer comprising means for directing a stream of substantially monoenergetic electrons onto the surface of a target electrode to be examined to produce scattered electrons; means forming a curved fluorescent screen electrode concentrically disposed around said target electrode for collecting certain ones of the target scattered electrons to form a diffraction pattern on said screen; means forming a curved grid structure concentrically disposed of said target electrode and screen electrode and interposed in the space therebetween for introducing a retarding field to prevent scattered electrons having less potential than a predetermined potential, related to the potential applied to said retarding grid, from reaching said fluorescent screen; a curved shield grid disposed between said retarding grid and the target electrode to be operated at substantially target electrode potential, said shield grid being disposed at a radial distance from said target electrode within a range of 30 to 80percent of the radial distance of said retarding grid from said target electrode, whereby the resolution of the spectrometer is enhanced.

2. The apparatus of claim **1** wherein said means forming a curved grid structure is a retarding grid electrode having grid openings defining electron passageways therethrough with characteristic diameters less than three times the characteristic lengths thereof whereby the retarding field potential is made substantially uniform across the electron passageways through said retarding grid for enhancing the resolution of the spectrometer.

3. The apparatus of claim **2** wherein said retarding field grid electrode comprises a pair of concentrically disposed grids with the spacing between said retarding field grids being substantially greater than the characteristic diameter of the apertures in said grids.

4. The apparatus of claim **1** wherein said means for directing a stream of monoenergetic electrons onto the surface of the target includes an elongated conductive tube for containing an electron gun assembly, said tube projecting radially through aligned apertures in said screen and retarding grid electrode structures toward the target, and the inner end of said gun tube terminating substantially at the inner concave surface of said retarding grid.