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(54) X-Ray focusing/electron gun combination.

(57) A focused x-ray module has a cathode (11), an anode (target) (21), and a point source focusing element (31). The cathode electron source is adapted to emit electrons to the anode target. The anode target is collinear with and spaced from the cathode electron source, and is capable of emitting X-rays when excited by electrons from the cathode electron source. The point source focusing element is formed from a section transverse to the axis of rotation of an ellipse. The axis of rotation of the ellipse is the straight line from the cathode electron source to the anode target which is at a first focus (s) of the ellipsoid. The focusing element has a focusing surface and a plurality of layered pairs formed on one another on the focusing surface. The layered pairs have X-ray dispersive properties within a wavelength range of interest, whereby to focus X-rays within the wavelength range of interest to a sample (40) at a second focus (s') of the ellipsoid. The second focus (s') is also on the axis of rotation.

EP 0 262 834 A2

X-RAY FOCUSING RING/ELECTRON GUN COMBINATION

Field of the Invention

The invention relates to x-ray analyses e.g., powder x-ray diffraction and photoelectron spectroscopy, and to apparatus for x-ray analyses, e.g., powder x-ray diffraction and photoelectron spectroscopy. More particularly the invention relates to x-ray sources for x-ray analyses, e.g., powder x-ray diffraction and photoelectron spectroscopy.

Background of the Invention

Layered synthetic material point source x-ray focusing devices i.e., focusing rings, are described in U.S. Patent 4,525,853 to John E. Keem and Gerald F. Marshall for Point Source X-Ray Focusing Device, incorporated herein by reference. As there described, the point source x-ray focusing devices collect, reflect, and concentrate the maximum x-ray flux from a point source to a focus point for a particular range of x-ray wavelengths of interest.

This is accomplished by the use of an ellipsoid of revolution focusing element, formed from a section transverse to the axis of revolution of an ellipsoid. The ellipsoid of revolution focusing element has an inner focusing surface made up of layered synthetic materials. That is, the inner focusing surface of the ellipsoid of revolution is made up of alternatively repeating layers of a metal and either a non-metal or a light element, as described for example in U.S. Patent Application (Case 1116.1) SN 547,338, John E. Keem and Steven A. Flessa entitled "Improved Reflectivity And Resolution X-Ray Dispersive And Reflective Structures And Method of Making the Structures", incorporated herein by reference.

As described in the aforementioned U.S. Patent 4,525,853, the anode is a point source at one focus, s, of the ellipsoid and the sample holder or the specimen is at the focus point or complementary focus, s′ of the ellipsoid.

Point source x-ray focusing devices, having focusing surfaces of synthetic layered materials, have attained wide commercial acceptance. They have been used for various methods of x-ray chemical and structural analysis, including powder diffraction analysis and photoelectron spectroscopy, e.g. electron spectroscopy for chemical analysis.

A problem associated with focusing rings has been the high cost of retrofitting many existing systems. This high cost is associated with the predetermined geometry of the system to be retrofitted, and the sensitivity of the focusing ring to the geometry. It has heretofore been necessary to tailor a specific focusing ring system to the specific x-ray system and the specific analysis. This is a commercial limitation requiring a different focusing ring for every combination of analysis and prior art focusing element therein to be replaced.

The predetermined geometry, and sensitivity of the system and focusing ring to that geometry is indicated in the paper of Gerald F. Marshall, "A Unified Geometrical Insight for the Design of Toroidal Reflectors with Multilayered Optical Coating: Figures X-Ray Optics," Proceedings of SPIE-The International Society for Optical Engineering, vol. 563, pp. 114-134 (1985), and Gerald F. Marshall, "Monochromatization by Multilayered Optics on a Cylindrical Reflector and on an Ellipsoidal Focusing Ring", Proceedings of other SPIE Vol. 691 pp 58-68 (1986), both incorporated herein by reference. The geometric problems associated with retrofitting include the fixing location of the sample holder for the specimens, the fixed location of the x-ray tube, the fixed location of the anode-target, and the fixed location of the prior art focusing element.

Summary of the Invention

The problems of prior art focusing rings and more particularly the problems of adapting prior art focusing rings for retrofit to existing x-ray analysis systems are obviated by the method and apparatus of the present invention.

The present invention provides a self contained, focused x-ray tube, i.e., a module with the focusing ring, the electron gun, the anode-target, and the sample holder in one integral unit. The focusing ring is a point source focusing element formed from a section transverse to the action of rotation of an ellipsoid. The ellipsoid of rotation has a first focus s, and a second focus s′ the axis of rotation of the ellipsoid. The axis of rotation of the ellipsoid is a straight line from the sample holder to and through the cathode electron source to the anode-target. The anode-target is at the first focus of the ellipsoid s and the sample holder is at the second focus of the ellipsoid s′.

The focusing ring has a focusing surface with a plurality of layer pairs formed on one another on the focusing surface. The layered pairs have x-ray dispersive properties within a wavelength range of interest, whereby the focused x-rays within the wavelength range of interest are sharply focused on the second focus of the ellipsoid.

The cathode electron source and the anode electron target are co-linear with each other on the ellipsoid axis of rotation. The cathode electron source is substantially within the focusing ring and adapted to emit electrons along the axis of rotation of the ellipsoid to the anode electron target.

The anode-target is material that emits x-rays at a desired wavelength, for example an aluminum K-alpha or magnesium K-alpha target. The cathode electron source of electron gun emits electrons. For example it may be a tungsten filament capable of emitting electrons at incandesence.

The point source focusing element or focusing ring has layered pairs formed of alternating first and second layers. The individual layers have an electron density difference therebetween and a d spacing associated therewith as described in the aforementioned U.S Patent Application Serial No. 547,338. The focusing ring for example may have layered pairs formed of non-metal chosen from the group consisting of beryllium, boron, carbon, silicon, germanium, and compositions thereof. The second layer comprises or a metal or alloy whereby to provide an electron density difference there between.

The members of the layered pair, that is the non-metal and metal, are further selected so as to provide chemical stability and an interfacial chemical stability and interfacial roughness. This involves utilizing materials having a low enough difference in Pauling electrongativity to avoid substantial chemical reactivity therebetween, and a low enough difference in atomic diameter and bond length to avoid diffusion therebetween. This is described more particularly in commonly assigned U.S. Patent Application Serial No. 547,338. Generally, the metal of the layer pair is hafnium, rhenium, tungsten, and alloys thereof.

The Figures

The invention may be understood by reference to the Figures.

Figure 1 is an isometric partial phantom view of is a self-contained, focused x-ray tube.

Figure 2 is an isometric partial phantom view of a photoelectron spectroscopy module of Figure 1 showing selected ray paths of the electron gun beam, the x-rays, and the photons emitted from the sample.

Figure 3 is a schematic plan view of a photoelectron spectroscopy module of Figure 1 showing the electron and x-ray paths.

Figure 4 is a cutaway plan view of a photoelectron spectroscopy module of Figure 1 showing the principle optical and x-ray components thereof.

Figure 5 is a cutaway side elevation of the focusing ring with two layered pairs show in exagerated scale transverse to the axis of rotation of the ellipsoid.

Detailed Description of the Invention

Figure 1 shows an x-ray focusing module 1 having a container 5 with a focusing ring 31 therein. Shown within the focusing ring 31 is an electron gun 11 powered by an electron gun power supply 13. At one end of the module 1, e.g. the first focus s is an x-ray target 21. The x-ray target 21 has a power supply.

At the opposite end of the module 1 is a sample opening and sample holder located at the second or complementary focus s'. Detectors, for example, detector rings or detector element 61 are shown. These detectors collect the emitted photons from the sample 41.

Figure 2 illustrates the optical pathway in the photoelectron spectroscopy module 1. Electrons are emitted by the electron gun 11. These electrons go along the axis of rotation 3 to the anode x-ray target 21. At the anode x-ray target 21 the electrons interact with the target material to emit x-rays 5.

These x-rays, 5, emitted from the target 21 are reflected off of the focusing ring 31 to the sample 41. The sample 41 emits secondary photons 7 which are measured in detector 61.

Figure 3 more particularly shows the ray paths from a hypothetical point 12, on the axis of rotation 3, of the electrons 4 to the anode target at focus s, 20, and of the emitted x-rays 5 from focus s, 20, to the focusing ring 31. The x-rays are focused by the focusing ring 31 to focus s', 40.

Figure 4 substitutes the components of the module 1 for the hypothetical geometric points of Figure 3. That is, in Figure 4 there are shown electron gun 11 for source 12, target 21 for focus 20, focusing ring 31, and sample 41 for focus 40.

Figure 5 shows the focusing ring 31 having two layered pairs 33 and 35. Each layered pair includes layered pairs 33a, 33b and 35a, 35b. One layer of the layered pair is a non-metal, e.g., chosen from the group consisting of beryllium, boron, carbon, silicon, germanium, mixtures, alloys, and compositions thereof. The other layer of the layered pair is formed from a metal of high electron density such as hafnium, rhenium, tungsten, mixtures, compositions, and alloys thereof.

The focused x-ray module has a cathode electron source 11 and an anode target 21, with the cathode electron source 11 being adapted to emit electrons 4 to the anode target 21. The anode target 21 is co-linear with the spaced from the cathode electron source 11. The anode target 21 emits x-ray 5 when excited by the electrons 4 from the cathode electron source 11.

The focused x-ray module 1 further includes a sample holder 40a capable of holding a sample 41.

The sample 41 can be moved in a plane perpendicular to the axis of rotation, e.g., by raster means 42. Within the focused x-ray module 1 is the point source focusing element formed of a focusing ring 31. The ring 31 is a section transverse to the axis of rotation 3 of an ellipsoid of rotation. The ellipsoid of rotation has a first force, s, (20), a second focus, s', (40) and a axis of rotation (3). The axis of rotation (3) of the ellipsoid is a straight line from the sample holder to and through the cathode electron source 11 to the anode target 21. The anode target 21 is at the first focus, s, (20) of the ellipsoid, and the sample holder 40a is at the second focus, s', (40) of the ellipsoid.

The focusing element has a focusing surface on the focusing ring 31 having of a plurality of layered pairs formed one on another on the focusing ring 31. The layered pairs have x-ray dispersive properties within a wavelength of interest, generally a wave length range within a broad range of from about 7.5 Angstroms to about 129 Angstroms. The absorption edges and fluorescenses of the materials making up the layered pair are outside the wavelength range of interest.

The anode target 21 of the photoelectron spectroscopy module 1 is a material that emits k alpha x-rays, for example, aluminium k alpha x-rays or magnesium k alpha x-rays.

The electron source within the cathode 11 is a material that emits electrons when suitably excited, for example a tungsten source that emits electrons at incandescence.

The focused x-ray module of the invention described herein is particularly useful in retrofitting existing x-ray analysis systems to carry out x-ray analyses with a focused x-ray module. The focused x-ray module may be used with expense adjustments to existing equipment.

In these analyses electrons are excited from the cathode electron source 11 to the anode electron target 21, causing the anode target 21 to emit x-rays. The x-rays are emitted from the anode target 21 to the specimen 41 by menas of the point source focusing element 31.

The reflected x-rays excite electrons within the sample at the second focus, s', which cause photons having a spectrum unique to the material of the sample to be emitted.

While the invention has been described with respect to certain preferred exemplifications and embodiments, thereof it is not intended to limit the scope of the invention thereby solely by the claims appended hereto.

Claims

1. In a focused x-ray module (1) comprising:

(a) a cathode electron source (11) and an anode electron target (21), the cathode ' electron (11) source being adapted to emitt electrons to the anode target (21), the anode target (21) being collinear with and spaced from the cathode electron source (11) and capable of emitting x-rays when excited by electrons from the cathode electron source (11); and

(b) a sample positioning means (40); characterized in that said focused x-ray module includes: a point surface focusing element (31) formed from a section transverse to the axis of rotation of an ellipsoid of rotation, the ellipsoid having a first focus, s, a second focus, s', and an axis of rotation, the axis of rotation of the ellipsoid being the straight line from the anode target adapted to be at the first focus, s, of the ellipsoid to the sample holder (40) adapted to be at the second focus, s', of the ellipsoid of rotation, the focusing element (31) having a focusing surface and a plurality of layered pairs (33, 35) formed on one another on said focusing surface, the layered pairs (33, 35) having x-rays dispersive properties within a wavelength range of interest, whereby to focus x-rays within the wavelength range of interest to the second focus, s', of the ellipsoid on the axis of rotation thereof.

2. The focused x-ray module of claim 1 wherein the anode target is chosen from the group consisting of Al K alpha and Mg K alpha.

3. The focused x-ray module of claim 1 wherein the cathode electron source (11) is a tungsten filament capable of emitting electrons at incandesence.

4. The focused x-ray module of Claim 1 where the point source focusing element (31) comprises layered pairs (33, 35) formed of alternating first and second layers, said individual layers having an electron density difference therebetween, and said layered pair having a d spacing associated therewith.

5. The focused x-ray module of Claim 4 wherein the point source focusing element (31) comprises layer pairs (33, 35) formed of a non-

metal chosen from the group consisting of Be, B, C, Si, Ge, and compositions thereof, and a second layer comprising a metal, whereby to provide an electron density difference therebetween.

6. The focused x-ray module of Claim 5 wherein the metal is chosen from the group consisting of Hf, Re, W, and alloys thereof.

7. An x-ray photoelectron spectroscopic method of chemical analysis of a sample carried out with the focused x-ray module according to any one of the preceding claims, the method comprising the steps of:

(a) exciting electrons from the cathode electron source (11) to an anode target (21) that is collinear with and spaced from the cathode electron source (11);

(b) emitting x-rays from the anode target (21);

(c) reflecting the emitted x-rays from the anode target (21) to a specimen (40) by means of a point source focusing element (31) formed from a section transverse to the axis of rotation of an ellipsoid of rotation, the axis of rotation of the ellipsoid of rotation being the straight line from the anode target (21) adapted to be at a first focus, s, of the ellipsoid of rotation to sample holder means (40) adapted to be at a second focus, s', of the ellipsoid, the focusing element (31) having a focusing surface and a plurality of layered pairs (33, 35) formed on one another on said focusing surface, the layered pairs having x-ray dispersive properties within a wavelength range of interest, whereby to focus the x-rays within the wavelength range of interest to the sample in a sample holder at the second focus, s', of the ellipsoid on the axis of rotation thereof;

(c) exciting photons from the sample (40) at second focus s'; and

(d) determining the energy distribution of the excited photons from the sample.

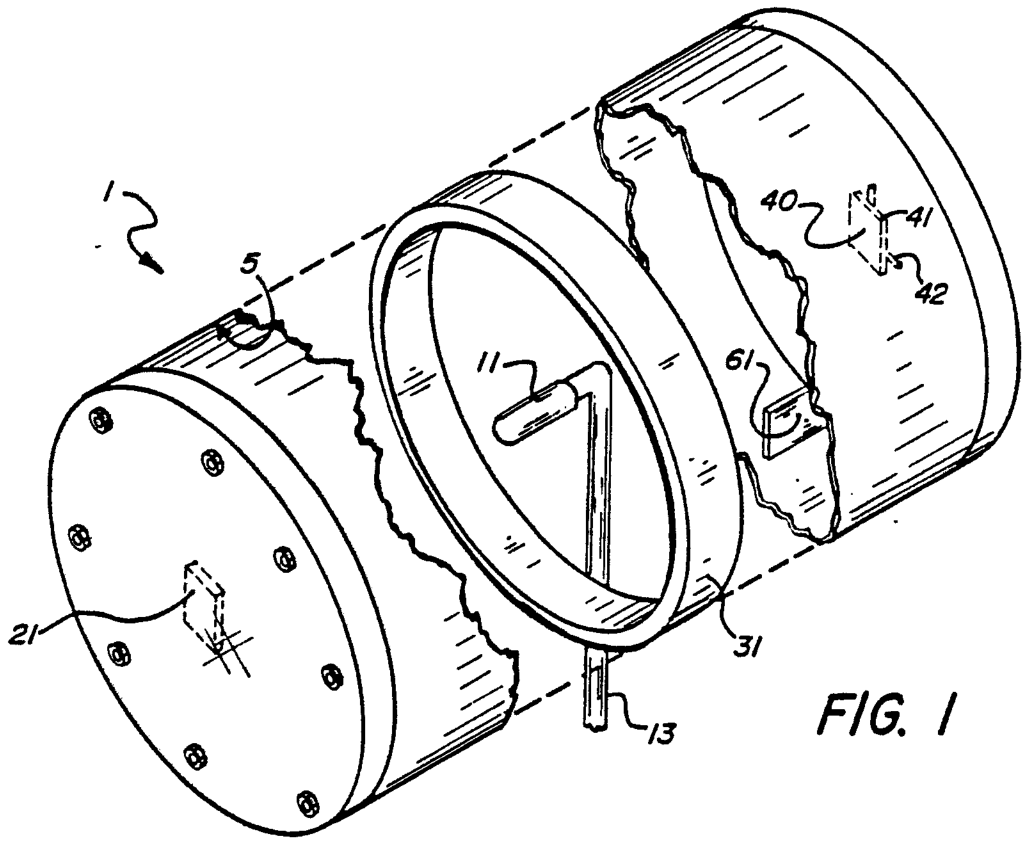
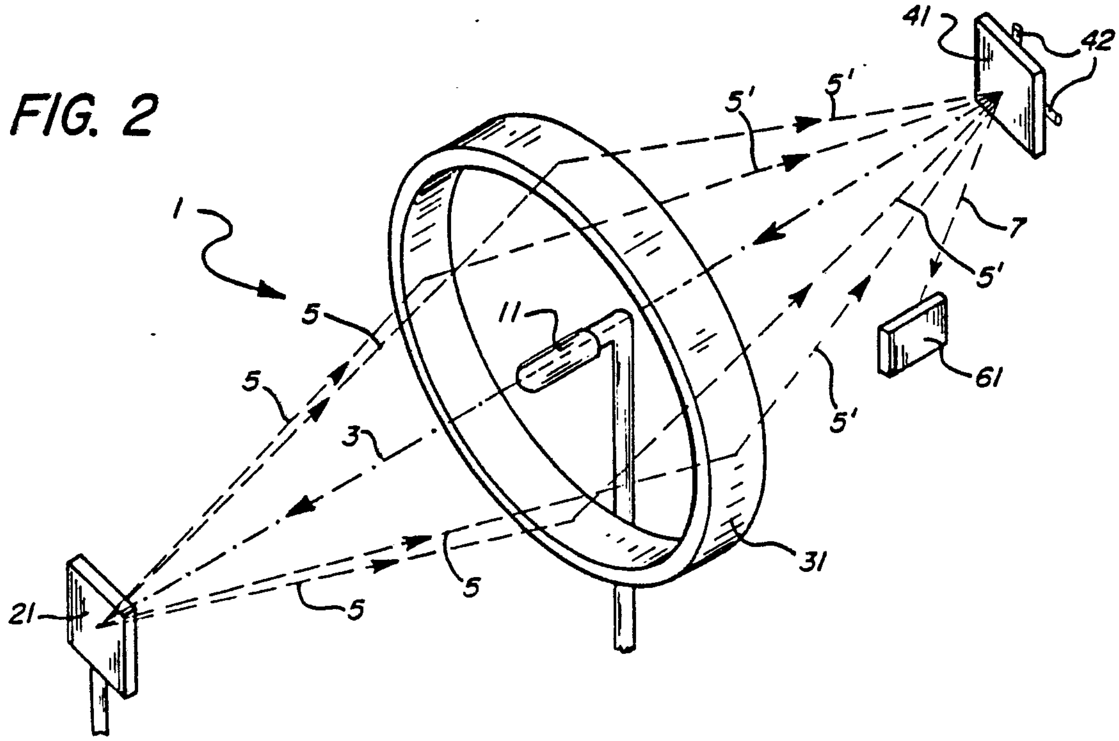


FIG. 1

FIG. 2



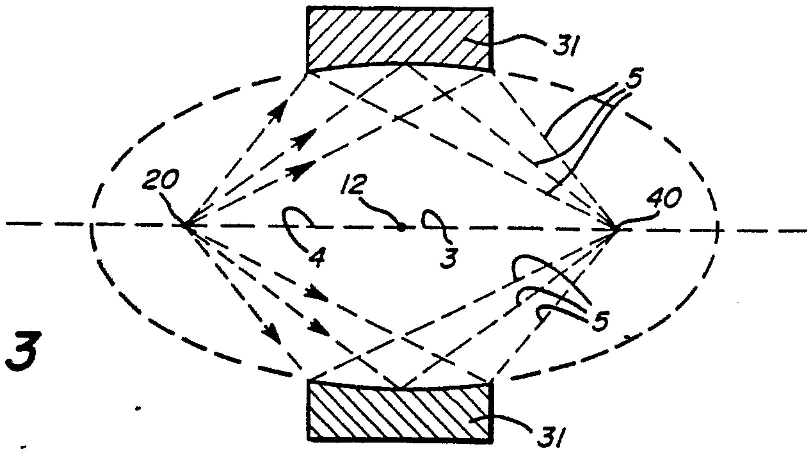


FIG. 3

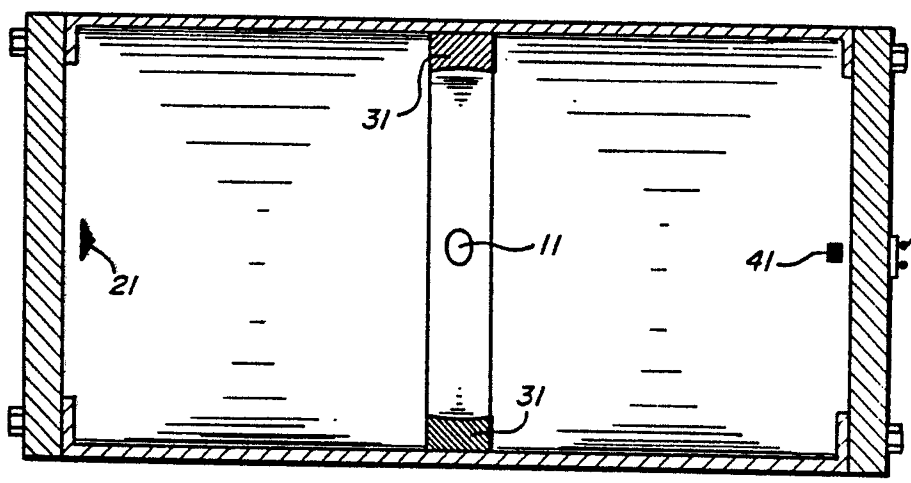


FIG. 4

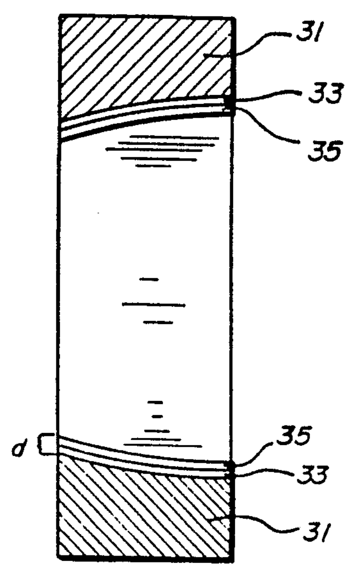


FIG. 5