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Coates et al.

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[54] **LOW VOLTAGE FIELD EMISSION SCANNING ELECTRON MICROSCOPE**

[75] Inventors: **Vincent J. Coates**, Los Altos; **Leonard M. Welter**, Saratoga, both of Calif.

[73] Assignee: **American Optical Corporation**, Southbridge, Mass.

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[52] **U.S. Cl.** ..... **250/49.5 C**, 250/49.5 A

[51] **Int. Cl.** **H01j 37/26**

[58] **Field of Search** ..... 250/49.5 A, 49.5 C

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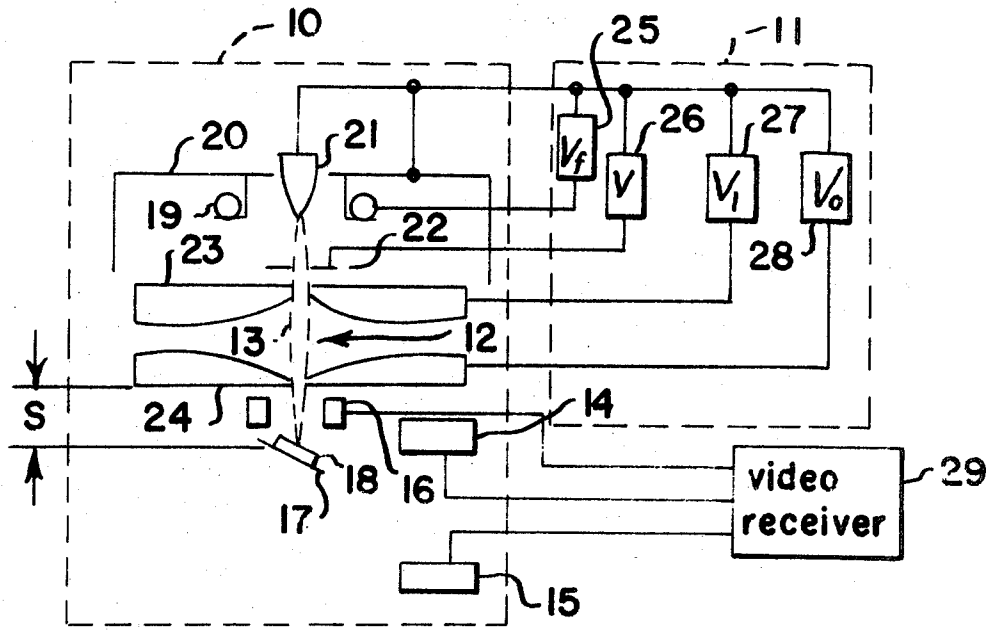
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Primary Examiner—James W. Lawrence
Assistant Examiner—Harold A. Dixon
Attorney—Howard R. Berkenstock, Jr. and William C. Nealon

[57] **ABSTRACT**

A Field Emission Scanning Electron Microscope having a field emission tip for generating charged particles and being axially aligned with an electrode and with an intermediate electrode interposed there between. The electrode and the intermediate electrode forming a field lens for focusing the charged particles from the field emission tip. Appropriate voltages are applied for providing extraction, acceleration and focus fields. The electrode potential being lower than the intermediate electrode potential with respect to the charged particles and selected to provide a real focus of the charged particles at a position outside the lens field and distal of the field emission tip thereby producing an intense beam of low energy particles.

16 Claims, 4 Drawing Figures



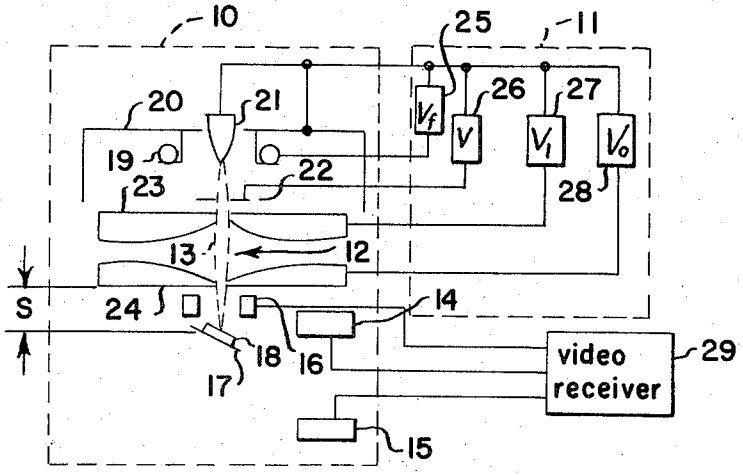


FIG. 1

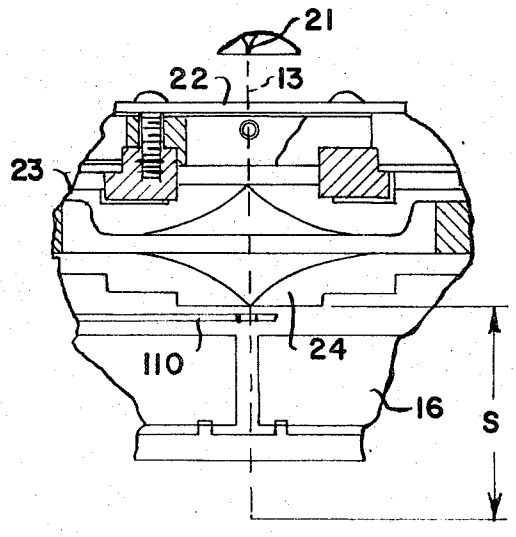


FIG. 3

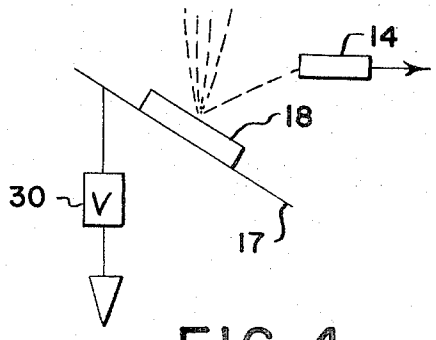


FIG. 4

INVENTORS
Vincent J. Coates
Leonard. M. Welter
BY
Attorney

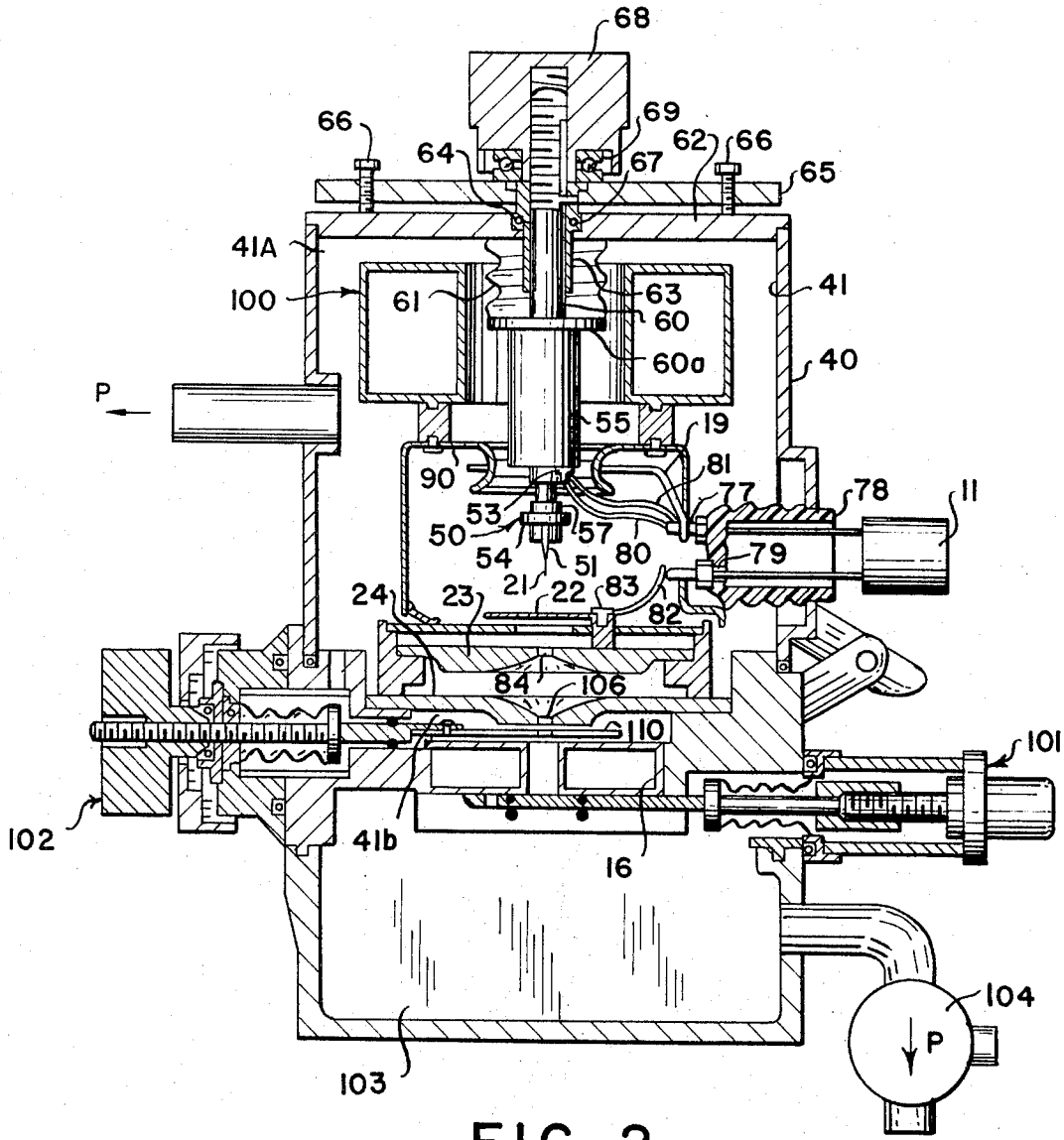


FIG. 2

INVENTORS
Vincent J. Coates
Leonard M. Welter
BY
Attorney

LOW VOLTAGE FIELD EMISSION SCANNING ELECTRON MICROSCOPE

BACKGROUND OF THE INVENTION

The invention relates in general to electron optical systems and more particularly to a field emission Electron Gun capable of producing a low voltage intense beam of focused electrons. In the applicant's co-pending patent application Ser. No. 46,425 filed June 15, 1970 now U.S. Pat. No. 3,678,333 there is described a Scanning Electron Microscope employing a field emission tip as its source of electrons. The use of the field emission tip allows the formation of a high intensity focused beam of charged particles providing the intense illumination needed in scanning microscopy. This co-pending application is principally directed toward a system which will provide and maintain the high vacuum requirements (in the neighborhood of 10 to the −9 torr) and high voltage protection necessary to acheiving a reliable high resolution Field Emission Scanning Electron Microscope. Normally the accelerating voltages used in the operation of the described Scanning Electron Microscope as well as other similar devices presently used in the art ranges between 1,000 and 100,000 volts. The same range of accelerating voltages is applied and used in conventional Scanning Electronic Microscopes using thermionic or filament guns for supplying the necessary electrons. As may be readily appreciated, the use of such high accelerating voltages especially in the neighborhood of 100,000 volts produces a myriad of problems. The specimen is often damaged by beams containing such high energy particles and in many instances the morphology of the specimen is so seriously altered as to create doubt as to the validity of the information obtained. In yet other instances when studying nonconductive surfaces the use of high energy beams will cause "charge up" conditions i.e., electrostatic charge build up on the surface from the electrons not being conducted away. In the instance of conventional thermionic guns, attempts to lower the accelerating voltage produces a drastic reduction in beam current intensity due to electron optical effects and the spot size increases, both ultimately producing a loss of desired resolution. In the case of conventional Scanning Electron Microscopes of the Field Emission type while markedly improved from an intensity and spot size point of view, the focus of the beam becomes a virtual image or a real image within the field of lenses and thus cannot impinge upon the specimen to be investigated. The applicants have discovered a novel means of producing a real image of an intense beam of low energy particles having a focus plane in the specimen holding portion of the Scanning Electron Microscope.

It is therefore an object of this invention to produce a low voltage Field Emission Scanning Electron Microscope producing a low energy high intensity beam of charged particles. It is another object of this invention to provide a method for producing a low energy high intensity beam of charged particles in a Scanning Electron Microscope. It is another object of this invention to provide a Field Emission Scanning Electron Microscope capable of producing a low energy high intensity beam of electrons. It is another object of this invention to provide a Field Emission Scanning Electron Microscope having a greatly reduced propensity for high voltage breakdown. It is yet another object of this invention

to provide a Scanning Electron Microscope for viewing specimens susceptible to beam damage. Yet, another object of this invention is to provide a Scanning Electron Microscope particularly useful in mirror scanning of a specimen.

SUMMARY OF THE INVENTION

As contemplated by the applicant's invention, there is provided a field emission tip gun for supplying or generating charged particles to be normally employed in a Scanning Electron Microscope. A final electrode is axially aligned with the field emission tip and another intermediate electrode is interposed between the field emission tip and the final electrode. The final electrode and the intermediate electrode together form a field lens which acts upon the beam produced by the charged particles generated from the tip. Essentially, the field lens substantially focuses the charged particles to a spot in a plane useful for viewing a specimen under investigation. A source of electrical potential supplies voltages to the field emission tip, the final electrode and the intermediate electrode for providing extraction, acceleration and focus fields necessary to formation of a charged particle beam and its ultimate focus. The electrode potential is lower than the potential of the intermediate electrode with respect to the charged particles forming the beam and is selected to provide a real focus of the charged particles at a position outside of the lens without a need for further lensing. This beam focus is at a point distal of the field emission tip and provides an intense beam of low energy particles for viewing the specimen.

In another aspect of the applicants' invention there is contemplated a method for producing a low energy high intensity beam of charged particles from a Field Emission Gun employing a field emission tip as the source of the charged particles. In conformance with this method, extraction accelerating and focusing potentials are applied to an axially aligned field emission tip, final electrode and intermediate electrode. The intermediate electrode being interposed between the field emission tip and the final electrode. The application of these fields serving to form and focus a beam of charged particles generated from the field emission tip. The final electrode potential is selected so as to form a negative lens field with the intermediate electrode with respect to the charged particles thereby producing a real focus of said charged particles outside the lens field and distal of the field emission tip without a need for further focusing. The particles at the spot focus of the beam are of a low energy high intensity character.

For a better understanding of the present invention together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings while its scope will be pointed out in the appended claims. It is emphasized that the preferred embodiments herein described are intended to be illustrative of the applicants' invention and in no way delimiting of its scope.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a functional schematic diagram of a Field Emission Scanning Microscope embodying the applicants' invention.

FIG. 2 is a cross sectional view of a typical Field Emission Scanning Electron Microscope.

FIG. 3 is a fragmentary view of an electrode arrange-

ment useful in the practice of the applicants' invention.

FIG. 4 is a functional schematic diagram of a specimen being viewed in a particular mode of use of the applicants' Field Emission Scanning Microscope.

Conventional symbols are used throughout the drawings and like numbers are used for like or similar parts in each view. These drawings are intended to be illustrative and exemplary of the invention and thus may not always conform to the actual practical embodiments but rather are shown to best point out the applicants' novel contribution to the state of the art.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The electron optical system of FIG. **1** is in a form of a Scanning Electron Microscope **10** embodying therein a field emission gun capable of conforming to the applicants' invention. It is significant at this juncture to point out while the Field Emission Gun of the illustrative embodiment is used to produce electrons as the illuminating particles, it is both possible, and in some instances necessary that the same source be used to produce other charged particles such as positive ions for viewing specimens of a particular nature or for obtaining information not readily ascertained from the use of an electron beam. When using a Field Emission Gun as a source of positive charged particles, it is necessary of course that the extraction voltages and the focusing fields be reversed to provide the necessary extraction, acceleration and focusing forces. Ancillary to the Scanning Electron Microscope there is shown a potential source **11** which means provides the various levels of voltages to the electrodes of the Scanning Electron Microscope **10** configuration necessary to the operation of the instrument. A second ancillary unit the video receiver **29,** in combination with the scanning and detector portions of the Scanning Electron Microscope **10** displays the desired view of the specimen undergoing investigation.

The field emission tip **21** constitutes the heart of Field Emission Scanning Electron Microscopy systems. It produces the highly coherent high intensity supply of electrons capable of being focused to a spot of desired resolution at the image plane to illuminate the specimen **18.** The specimen **18** is shown mounted to a specimen holder **17** which positions the specimen **18** with respect to the focused beam of electrons **13.** The beam of electrons or charged particles **13** is primarily formed by the action of anodes **23** constituting an intermediate electrode interposed between the field emission tip **21** and an electrode **24** located distal of intermediate electrode **23** with respect to the field emission tip **21.** The electrode **24** and the intermediate electrode **23** form in combination a field **12** acting as a focusing lens on the beam **13** as it passes through the electrode apertures toward the target or specimen **18.**

The main accelerating voltage V0 is provided by voltage or potential means **28** to the electrode **24** and its magnitude is selected relative to the potential of field emission tip **21.** When used as a Scanning Electron Microscope, the potential of the electrode **24** is normally positive, thereby providing an accelerating voltage to the charged particles; namely, the electrons. The potential source **27** provides a voltage V1 to the intermediate electrode **23** which potential is normally less or lower than the potential of electrode **24** with respect to the charged particles forming the beam **13.** Thus, there is provided in normal operation a positive field between the electrode **24** and the intermediate electrode **23** tending to converge the beam **13** toward a focus at the specimen plane **18.** A last electrode, namely extraction electrode **22** is placed closest to the field emission tip **21** and like electrode **23** and intermediate electrode **24** has a centrally located aperture axially aligned with the field emission tip **21.** The beam **13** is formed by the passage of the charged particles from the field emission tip **21** through the apertures in extraction electrode **22** and intermediate electrode **23** and electrode **24** respectively. The potential source **26** provides a voltage substantially equal to the voltage V1 of potential source **27** and provides the extraction field for the field emission tip **21.** When used in the electron mode, this voltage is of course positive and produces an extremely high field intensity in the neighborhood of the field emission tip **21** which has an ultimate tip having a radius approximately 1,000A. Of course, it is recognized that when used as a source of positive charged particles then the voltage V must be reversed in potential causing an oppositely polarized field having the necessary intensity to form ions or other charged particles.

The lens system **16** is primarily intended for control of the beam **13** for scanning the specimen **18** in the programmed manner. Essentially, the lens system **16** constitutes deflection plates synchronized to the scanning system of the video receiver **29,** thereby locking in the scanning of the specimen **18** and the scanning of the video field of the receiver **29.** Detectors **14** and **15** are placed so as to receive or detect information obtained from the surface or through the specimen **18.** Information about the specimen **20** may be obtained by detecting transmitted electrons as in the case of a transmission electron microscope, secondary electrons, reflected electrons, absorbed electrons, photons or x-rays, any and all of which are generated by the incident electron or other charged particle beam. These detectors **14** and **15** which are most frequently of the scintillation type are used to detect one of the information signals which is then used to modulate the intensity of the synchronously scanned display tube of the video receiver **29** which includes a sweep generator to form an image of the specimen **18.** Throughout the remainder of this specification and particularly when considering operative examples or modes of operation, the apparatus will only be considered when used in the electron mode i.e., only when field emission tip **21** is used to generate electron particles. This is not, however, intended to delimit the inherent symmetry of the systems when used in either of the two modes.

The remaining elements of FIG. **1** are a discharge shield **20** and a sublimation coil **19.** The discharge shield **20** finds primary utilization in preventing high voltage discharges from the outer chamber **40** to the extraction electrode **22** and the field emission tip **21,** additionally this shield serves as a condensing structure for titanium or other material of suitable character sublimated from the sublimation coil **19.** When the sublimated material condenses on the surface of the shield **20,** it provides a material which reactively combines with gaseous components in the neighborhood of the field emission tip thereby lowering the vacuum. The sublimator coil **19** is of course part of a vacuum pumping system which in combination with the inherent ion pumping in the neighborhood field emission tip **21** maintains a vacuum in the order of 10 to the −9 to 10

to the −10 torr thereby assuring prolonged and reliable operation of the field emission tip **21** as a source of electrons. It is note worthy to point out that the invention or novel contribution of the applicants' contained in this application to some degree obviates the need for the high voltage shield by reducing the accelerating voltage required to form a focused beam of high intensity electrons on the specimen **18** to be viewed.

Before passing to an operational description pointing out the most significant elements of the applicants' invention, the Field Emission Scanning Electron Microscope of FIG. **2** will be considered. Disposed within the vacuum chamber **41** and in specifically the high vacuum area **41A**, there is the field emission tip **21** comprising the source of electrons. This field emission tip **21** is normally an etched tip which does not employ any filament voltage or power to emit electrons but which rather depends upon the formation of an extraction field in the neighborhood of its ultimate tip which is in the neighborhood of 1,000A radius. When the field developed in this area is sufficiently large so as to overcome the work function of the metal which is normally tungsten and the retarding field developed by emitted electrons, the field emission tip **21** acts as a source for a highly coherent high intensity beam of electrons.

The field emission tip **21** is supported for movement along the X, Y and Z planes and for its removal for replacement. As shown in FIG. **2**, the tip support assembly **50** comprises a V-shaped mount **51** which has the tip **21** attached thereto. An insulator disc **54** receives electrode **53** which is attached to the tip **21** which electrode **53** is secured to the insulator disc **54** by a suitable fastener such as threaded member **57**. The tip **21**, the disc **54** and the electrode **53** are in the form of a plug in assembly which is detachably secured to the distal end of a post **55**. The upper end of the insulator post **55** is fixedly secured to a metal shaft **60** having an end cap **60***a* with a depending flange fixed within the upper end of the post **55**. A bellows **61** is welded to the cap **60***a* to form a vacuum wall or seal with the high vacuum chamber while permitting axial and transverse movement of the tip support assembly **50**. The bellows **61** is welded directly to an end cap **62** to complete the vacuum seal. Surrounding the shaft **60** is a sleeve **63** which is located in an opening **64** of the cap **62**. Spaced from the cap **62** is a support plate **65** that has a suitable opening therein for receiving the shaft **60** and the sleeve **63**. A knob **68** in threaded engagement with the upper end of the shaft **60** produces axial movement of the tip assembly **50** while adjustment screws **66** tilt the plate **65** thereby producing motion in the X, Y plane for alignment with the apertures of the various anodes of the microscope; namely, extraction electrode **22**, the intermediate electrode **23** and electrode **24**.

Spaced downstream from the tip **21** in a low vacuum area **41b** of the vacuum chamber **41** is the intermediate electrode **23** having a central aperture opening **84** aligned with the field emission tip **21**. A second electrode **24** is located further downstream of intermediate electrode **23** and in similar fashion has its aperture **106** axially aliged with the field emission tip **21**.

A third electrode or more appropriate discharge shield **90** is diposed within the high vacuum area **41A** surrounding or protecting the field emission tip **21** from premature failure due to electrical high voltage discharge. The discharge shield **20** is connected to an output terminal **77** of the high voltage insulator coupling **78**. Thus, it is substantially at the same electrical potential as the field emission tip **21** as shown in FIG. **1**. The fourth electrode or extraction electrode **22** located within the chamber **41** is disposed substantially within the discharge shield **20**. When voltage is applied to the extraction electrode **22**, an extraction field is created and electrons are drawn from the field emission tip **21**. It is the extraction electrode **22** that permits normal electron emission when the discharge shield **20** is deployed about the field emission tip **21** for protection from excessive voltage transients. The voltages for supplying the proper potentials to the electrodes of the electron gun are provided by a voltage supply **11** connected to the vacuum chamber through terminals **77** and **79** by means of high voltage coupling **78**. The terminal **77** is connected to the electrode **43** as well as to the shield or discharge electrode **20**. The terminal **79** which is the high voltage or potential source V of FIG. **1** is connected over a conductor **82** to the extraction electrode **22** which is in turn connected to the intermediate electrode **23** through a voltage dropping resistor **83**. This voltage dropping resistor **83** serves to maintain the extraction electrode **22** voltage at a normal V when subjected to high voltage discharge. This maintenance of the extraction electrode **22** at a V voltage prevents discharge over from the extraction electrode **22** to the field emission tip **21** and the resultant failure of the tip itself.

Assembly **102** of FIG. **2** constitutes an insertion device for aperture size control slide plate **110**. Depending upon the beam size required for the specimen under investigation and for the desired resolution the mechanism of **102** comprising an adjustment screw with appropriate sealing members such as bellows and O rings permits movement of the aperture size plate **110** across the axis of the housing electrodes until the desired size aperture is obtained. The lower chamber **103** is the specimen chamber itself. Within this housing, there is contained the specimen undergoing investigation as well as those detectors needed to obtain the necessary or desired information from the particle and specimens emissions. Chamber **103** is sealed to the main housing of the electron microscope through appropriate O ring sealing members. However, when a specimen change is required, in order to prevent contamination of the beam formation portions of the scanning electron microscope a mechanism **101** is employed. This mechanism **101** is similar to that of the aperture control mechanism **102** and comprises an adjustment screw arrangement with appropriate bellows and O ring sealing members to prevent leakage to the atmosphere. In essence this mechanism **101** constitutes a valve unit which slides across the opening through which the beam passes in the lens **16** thereby preventing leakage to atmosphere of of the main portion of the chamber **41** when the specimen chamber **103** is vented.

Ion pump **104** in combination with a sublimation getter pump **19** and an integral ion pumping action around and in the vicinity of the field emission tip **21** provides the necessary extremely low vacuum levels requisite to the proper performance of a field emission scanning electron microscope. Initial pumping to the level of approximately 10^{-7} is performed through the ion pump **104**. When reaching this approximate level, the remainder of the pumping action is performed by getter material sublimed from a sublimation ring **19**. Each is activated through the high voltage terminal **77**. The

sublimed material condenses on the inner portion or surface of the discharge shield **20** and either buries contamination molecules within itself or reactively combines to remove them from the atmosphere surrounding the field emission tip **21.** At the same time the electrons extracted from the field emission tip **21** cause ionization of gaseous molecules in its vicinity, which ions are then attracted to the discharge shield **20** and eventually burried within the sublimed material from the sublimator coil **19.** This gettering pump action combined with the integral ion pumping contained within the field emission tip electrode configuration maintains the field emission tip **21** in a contamination free environment and holds that same environment at the minimum pressure contained within the entire system approximately 10^{-9} to 10^{-10} torr. This results in stable field emission tip **21** operation and greatly extended life and reliability. Chamber **100** surrounding the field emission tip assembly **50** is a chamber for holding cryogenic fluids resulting in a cryogenic pumping action again in the vicinity of the field emission tip **21.** While this cryogenic tip action enhances the vacuum pumping action of the system, it is not necessary to proper performance of the equipment.

Considering the operational characteristics of a field emission scanning electron microscope employing the Applicant's novel contribution to the art, reference will be had to FIG. **3** which shows a typical electrode field emission tip configuration and geometry. In analyzing this typical configuration it must be remembered that it is typical of that found in the systems of FIGS. **1** and **2** and therefore contains the same ancillary equipment and electrical connections to potential energy sources. In FIG. **3,** there is shown a field emission tip axially aligned with apertures in the extraction electrode **22,** intermediate electrode **23,** and electrode **24,** respectively. Further, there is shown the lens system **16** for stigmatic correction and deflection of the beam and the aperture control plate **110.** In all scanning electron microscopes heretofore available an accelerating voltage between 5,000 and 100,000 volts was applied to the electrode **24,** a potential between 500 and 3,500 volts or 2,000 volts nominal was applied to the intermediate electrode **23** and approximately the same 2,000 volt nominal potential was applied to the extraction electrode **22.** These fields resulted in the formation of a beam of high intensity from the field emission tip **21** and produced a real focus of the beam at a distance S from the exit aperture of electrode **24.** It is noted at this point that the electrode geometry configuration conforms to the optimum shapes as calculated by J. W. Butler and described in a paper by A. V. Crewe, D. N. Eggenberger, J. Wall, and L. M. Welter entitled "Electron Gun Using a Field Emission Source," volume 39, No. 4, The Review of scientific Instruments, April, 1968, page 580. With electrode **24** and intermediate electrode **23** so configured; and with ratios of electrode **24** voltage **V0** to intermediate electrode **23** voltage **V1** between approximately **10** and **30;** and with axial electrode spacing of approximately 2 centimeters between the electrode **24** and the intermediate electrode **23;** and between one to three centimeters from intermediate electrode **23** to the field emission tip **21,** however, these distances may vary significantly for specific applications; a real image or focus of the beam **13** is formed downstream of the electrode **24** distally located from the field emission tip **21.** As the electrode **24** voltage **V0** is lowered toward a ratio of **10** with voltage **V1,** the image distance S proceeds toward infinity and thus fails to produce a usable spot size for scanning electron microscopy operation. As this same ratio of **V0** to **V1** increases above approximately **30,** the image distance S becomes negative and the focus is produced within the lens system comprising electrode **24** and intermediate electrode **23** and thus becomes unusable with respect to specimen investigation. In this range of voltage ratios between **10** and approximately **30,** it is evident that the electron beam is one of high intensity due to the operating characteristics of the field emission tip **21** and of relatively high energy thereof presenting the difficulties heretofore outlined in this specification.

The Applicants have discovered that as the ratio of **V0** to **V1** is continuously reduced that at the point **V0** becomes of lower potential than **V1** thereby producing a negative field within the lens system formed by electrode **25** and intermediate electrode **23** with respect to an electron particle, a real focus of the beam reoccurs outside the lens field and distal of the field emission tip **21,** obviously this focused beam is now usable for investigatory purposes with regard to the specimen. With regard to the particular lens configuration shown in FIG. **3,** it is found that when the electrode **24** voltage **V0** approaches approximately 300 volts with the intermediate electrode **23** voltage **V1** at approximately 2,000 volts or in other words a ratio of approximately 0.15 a real image is formed approximately 5 centimeters from the exit aperture of the electrode **24,** i.e., the image distance S equals 5 centimeters. The reason for the formation of this real focus at ratios of **V0** to **V1** of less than unity is not fully understood. However without in any way limiting the scope of the applicant's invention and without being bound in any way by the theories set forth herein, it is hypothesized that the negative field formed within the confines of electrode **24** and intermediate electrode **23** act upon the beam as a negative lens or mirror lens system and result in directing the beam electrons toward a focus in front of the electrode **24** when the beam comprises particles of sufficient energy to pass through the negative lens system and exit through the aperture of electrode **24.** Macro-analysis of the effect of a mirror lens system conforming to that of the system presented in FIG. **3** shows the feasibility of the hypothesis set forth. However, it must be clearly understood that such analysis is overly simplistic and that the actual reasons and theories forming a basis for the Applicants discovery may be significantly more complex and of entirely different nature.

Operating a field emission scanning electron microscope in the novel mode, above set forth, allows the achieving of a small focussed spot of electrons accelerated to only a few hundred volts but with electron beam currents which are about the same as those obtained at higher accelerating voltages. When used in this new mode, the field emission gun still retains the advantages described and set forth in this application as well as previously referenced copending application, Ser. No. 46,425. When operating in this mode, the scanning electron microscope offers a number of advantages. The voltages needed to operate the gun being of much lower value obviate the need for complex design procedures to avoid voltage discharges which can damage parts or disrupt operation of the microscope. This necessarily results in a lower cost and a more diversified field of use for the equipment as well as enhanced reli-

ability. Further the lower accelerating voltage V0 combined with the capability of producing a small spot size with high beam current allows the study of non-conducting specimens or objects without introducing the problem of "charge up" which is normally faced. It has been found that useful bright images can be obtained with V0 voltages as low as several hundred volts combined with tip voltages, i.e. V voltages of 5 or 10 times greater than this.

Yet another useful aspect of the applicant's invention consists of its use in studying specimens which cannot be submitted to actual contact with the energetic beam. In FIG. 4 there is shown the specimen holding portion of a system arranged so as to avoid actual contact of the beam with the specimen **18.** As shown, the beam focusses just above the surface of the specimen **18** and the deflected electrons are sensed by a detector **14** for display in the ancillary video receiver equipment **29.** The specimen holder **15** and thus the specimen itself **18** is biased by a voltage source V**30.** This bias voltage being selected to a value which is equal in magnitude and opposite in polarity to the accelerating voltage V0 of the system such that the electrons of the beam **13** are decelerated to a stop just above the specimen or object surface. By carefully controlling the specimen **18** bias it is possible to detect the deflected scanning electrons as a function of the topography of the surface or electro static or magnetic properties of the surface. This constitutes a non-destructive test procedure or inspection device of the specimen **18** surface since the beam **13** electrons do not in any way interact at a high voltage with the specimen **18.** Such mirror microscopy is made possible by the formation of the low energy beam with sufficient intensity to produce the desired resolution and contrast and finds particular value in instances where a hundred per cent inspection of parts is required but where no impingements of the beam may be allowed due to possible damage or interaction with the specimen. It also finds significant value when dealing with specimens that are of such a delicate nature that the energy of the beam itself may cause significant changes in the morphology of the substance.

Briefly in sum the Applicants have found that by applying an accelerating voltage V0 to the electrode **24** of a lower potential than the intermediate electrode **23** potential with respect to the charged particle comprising the beam to be focussed that there results an image of the beam formed at a point outside the focus field of the lens formed by electrode **24** and intermediate electrode **23** and distal of the field emission tip **21.** The discovery of this mode for operation of a Field Emission Scanning Electron Microscope has resulted in a device of significantly broader application and increased reliability. It provides a microscopy instrument long sought by the industry capable of scanning the morphology and topography of a specimen without subjecting a specimen to high energy particle impingement. It is reiterated and emphasized that the applicants' invention as set forth herein in the exemplary embodiments is intended to be illustrative of the apparatus and methods employed and is not intended to be delimiting of their scope. Thus, all those modifications and changes apparent to one skilled in the art are considered to be within the scope and ambit of the applicants' invention.

What is claimed is:

1. A Field Emission Gun comprising:

a field emission tip for generating charged particles;

a final electrode axially aligned with said field emission tip;

an intermediate electrode interposed between said field emission tip and said final electrode forming a field lens with said final electrode for focusing said charged particles generated by said field emission tip;

and potential means for supplying voltages to said field emission tip, said final electrode and said intermediate electrode for providing extraction, acceleration, and focus fields, said final electrode potential being lower than said intermediate electrode potential with respect to said charged particles and the ratio of said final electrode potential to said intermediate electrode potential being selected such that said field lens provides a real focus of said charged particles at a position outside of said field lens and distal of said field emission tip without further lensing, thereby producing an intense beam of low energy particles.

2. The Field Emission Gun of claim **1** wherein the charged particles are electrons extracted from said field emission tip by said extraction field.

3. A method for producing a low energy high intensity beam of charged particles from a field emission gun comprising the steps of:

applying extraction, accelerating and focusing potentials to an axially aligned field emission tip, a final electrode and an intermediate electrode interposed between field emission tip and said final electrode to form a beam of said charged particles;

and, selecting said final electrode potential sufficiently below said intermediate electrode potential with respect to said charged particles to form a lens field so as to produce a real focus of said charged particle beam outside said lens field and distal of said field emission tip without further focusing.

4. The method of claim **3** wherein said charged articles are electrons.

5. The method of claim **3** wherein said charged particles are electrons extracted from said field emission tip and wherein an extraction electrode is axially aligned with and in close proximity to said field emission tip and said extraction electrode voltage is approximately 2,000 volts, said intermediate electrode voltage is approximately 2,000 volts and said final electrode potential is approximately 300 volts.

6. The method of claim **3** wherein said charged particles are electrons extracted from said field emission tip and wherein an extraction electrode is axially aligned with said field emission tip and said extraction electrode and said intermediate electrode voltage is approximately at least 500 volts.

7. The method of claim **6** wherein the said final electrode, said extraction electrode and said intermediate electrode have apertures axially aligned with said field emission tip, said final electrode and said intermediate electrode form a lens field having an axial length of approximately 2 centimeters,

said extraction electrode is axially removed from said field emission tip by approximately 1 centimeter,

said final electrode potential is approximately 75 volts, and said real focus occurs at a position approximately 5 centimeters from said final electrode aperature.

8. A field emission gun comprising:

a field emission tip for generating electrons;

a final electrode aligned with said field emission tip;

an intermediate electrode aligned with said field emission tip and interposed between said field emission tip and said final electrode forming a lens with said final electrode for focusing said electrons generated by said field emission tip;

an extraction electrode aligned with and in close proximity to said field emission tip providing an extraction field for drawing electrons from said field emission tip; and

potential means for supplying potentials to said field emission tip, said final electrode, said intermediate electrode and said extraction electrode for generating said extraction field and acceleration and focus fields, said final electrode potential being lower than said intermediate electrode potential and the ratio of said electrode potential to said intermediate electrode potential being selected such that said lens forms a real focus of said electrons without further lensing at a position outside of said lens and distal of said field emission tip thereby producing an intense beam of low energy electrons.

9. The Field Emission Gun of claim **8** wherein said final electrode said extraction electrode and said intermediate electrode have apertures axially aligned with said field emission tip through which said intense beam of low energy particles passes.

10. The field emission gun of claim **9** wherein said ratio is approximately 0.15.

11. The field emission gun of claim **10** wherein the extraction field intensity is at least approximately 5 times 10^{+7} volts per centimeter.

12. The Field Emission Gun of claim **9** wherein said intermediate electrode voltage is at least approximately 500 volts, said field lens formed by said intermediate electrode and said final electrode has an axial length of approximately 2 centimeters, and said field emission tip is axially removed from said intermediate electrode a distance of approximately at least 1 centimeter.

13. The Field Emission Gun of claim **9** including integral pumping means operatively associated with said field emission tip for providing a contamination free environment for said field emission tip.

14. The Field Emission Gun of claim **13** including a sublimation pump for reactively combining with contaminant molecules in the environment of said field emission tip, and a cryogenic chamber for cryopumping contaminants from said environment of said field emission tip.

15. The field emission gun of claim **13** wherein said integral pumping means comprises electrons generated by said field emission tip and emitted from said extraction electrode for ionizing molecules in the area of said field emission tip.

16. The Field Emission Gun of claim **9** including biasing means for establishing the potential of a specimen located at said position for preventing impingement of said intense beam on said specimen.

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