



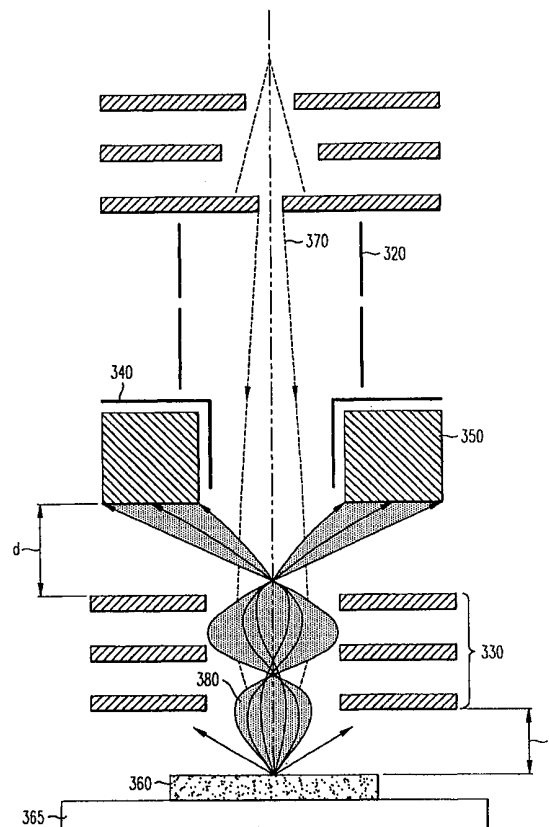
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁷ : H01J		A2	(11) International Publication Number: WO 00/31769
			(43) International Publication Date: 2 June 2000 (02.06.00)
(21) International Application Number: PCT/US99/27689			(81) Designated States: CA, IL, JP, KR, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).
(22) International Filing Date: 22 November 1999 (22.11.99)			
(30) Priority Data: 09/199,112 24 November 1998 (24.11.98) US			
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(54) Title: DETECTOR CONFIGURATION FOR EFFICIENT SECONDARY ELECTRON COLLECTION IN MICROCOLUMNS

(57) Abstract

A structure and associated method for detecting secondary and backscatter electrons in a microcolumn. A secondary electron detector and a backscatter electron detector, both located upstream of the Einzel (objective) lens in the microcolumn, provide a highly efficient axially symmetric electron detector, short column length, and short working distance. The secondary electron detector is located between the deflection system and the Einzel lens, between the suppressor plate and the Einzel lens, or between the deflection system and the beam-limiting aperture. The backscatter electron detector is located between a beam-limiting aperture and the deflection system and can be incorporated into the aperture. A secondary electron extractor placed between the sample and the Einzel lens further improves the spatial resolution caused by surface imperfection or local surface potential on the sample surface.



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DETECTOR CONFIGURATION FOR EFFICIENT SECONDARY ELECTRON
COLLECTION IN MICROCOLUMNS

FIELD OF THE INVENTION

This invention relates to electron beam microcolumns, and in particular to a micro-electron-beam-column equipped with secondary and backscatter electron detectors.

BACKGROUND OF THE INVENTION

Electron beam microcolumns based on microfabricated electron optical components and field emission sources operating under the scanning tunneling microscope (STM) aided alignment principle were first introduced in the late 1980s. Electron beam microcolumns are used to form a finely focused electron beam and offer the advantages of extremely high resolution with improved beam current, small physical size, and low cost, and can be used in a wide variety of applications, such as electron beam lithography. Microcolumns are discussed in general in the publications "Electron-Beam Microcolumns for Lithography and Related Applications," by Chang, T. et al., Journal of Vacuum Science Technology Bulletin 14(6), pp. 3774-3781, Nov./Dec. 1996; and "Experimental Evaluation of a 20x20 mm Footprint Microcolumn," by E. Kratschmer et al., Journal of Vacuum Science Technology Bulletin 14(6), pp. 3792-96, Nov./Dec. 1996, both incorporated herein by reference.

A microcolumn may be used as a general scanning electron microscope (SEM). A conventional SEM detects secondary electrons (SE) to generate its image. Generally, secondary electrons are of low energy and provide information as to the topography of a sample. Material contrast of the sample can be obtained using backscatter electrons (BSE), which are of high energy.

Secondary electrons are emitted from a surface when electrons from an electron beam source, such as a microlens system, impinge on the surface with sufficient energy. The direction and degree of secondary electron emission depends strongly on the surface geometry. Emission of high-energy back-scattered electrons can occur as well, depending on the surface material properties.

Fig. 1 (prior art) illustrates in a side view a conventional microcolumn detection scheme. The main components are: (a) an electron source 105 consisting of a cathode with one or more electrodes to extract and accelerate the emitted electrons to the desired energy, (b) an objective lens, typically Einzel lens 130, to form a focused beam, and (c) a deflection plate 120 for beam scanning. Secondary electron detector 150 is located between the last electrode of Einzel lens 130 and sample 160.

Primary electrons 170 are extracted from electron source 105, passed through a limiting aperture 110, accelerated to a final beam voltage of 1 keV and refocused with Einzel lens 130

onto sample 160. When a periodic voltage is applied to deflection plates 120, the focused primary beam 170 is swept across sample 160 and generates secondary electrons (SE) 180. Secondary electrons 180 which escape from the sample surface are emitted in a wide cone with a cosine distribution. Only a small fraction (shown as the shaded area) of secondary electrons 180 in the outer emission cone strikes the area of SE detector 150. The collected secondary electrons 180 are used to create a secondary electron image.

The yield of detected secondary electrons can be improved by increasing spacing w between SE detector 150 and sample 160. Fig. 2 (prior art) shows such an increased spacing w between SE detector 250 and sample 260. For example, if spacing s is 0.1 mm, working distance w is 1 mm, and SE detector 250 has an inner diameter of 1.5 mm, then only secondary electrons 280 emitted at angles larger than 83° reach SE detector 250, yielding a detector efficiency of less than 2%. However, if spacing s is increased to 1 mm, the detector efficiency increases to 39%. But the increase in spacing s requires a larger working distance w for Einzel lens 230, which results in a loss of spatial resolution due to increased aberrations.

Commonly, in order to improve the detector efficiency, a bias voltage is applied to the surface of SE detector 250, which attracts some of the secondary electrons which would be lost otherwise. This bias voltage has a minor influence on the focusing of primary beam 270, even when shield 240 is

incorporated. The applied bias does not significantly impact the collection efficiency of the backscattered electrons. A higher bias voltage, however, does increase the aberrations and therefore degrades the spatial resolution.

Accordingly, a microcolumn structure which increases the detection yield of secondary electrons, improves the signal-to-noise ratio and improves the spatial resolution due to the decrease in work distance is needed.

A backscatter electron (BSE) detector provides information as to the material contrast of a sample and is an optional device. Conventionally, a single detector is used to detect both the secondary electrons and the backscatter electrons and the SE/BSE detector is generally mounted directly to the bottom of the objective lens.

In order to have the best geometric collection efficiency for BSE detection, the BSE detector needs to be mounted as high as possible above the sample. However, by raising the BSE detector, the objective lens needs to be raised as well. As discussed above, an increased working distance for the Einzel lens results in a loss of spatial resolution. In addition, because the secondary electrons are of low energy, when the SE detector is placed too far away from the sample, a greater number of electrons are lost before reaching the SE detector.

Therefore, a microcolumn structure is needed to detect high energy backscattered electrons with high efficiency.

SUMMARY OF THE INVENTION

In accordance with the present invention, a structure and an associated method for detecting secondary and backscatter electrons are provided. In the present invention, a pre-Einzel lens secondary electron detector (i.e. located upstream of the Einzel lens with respect to the direction of the electron beam) and a pre-Einzel lens backscatter electron detector, separate from the SE detector, provide a combination of a highly efficient axially symmetric electron detector, short column length, and short working distance.

In one embodiment, the SE detector is placed upstream of the Einzel lens, between the deflection system and the Einzel lens. In one embodiment, the SE detector is placed upstream of the Einzel lens, between the suppressor plate and the Einzel lens. The shield for the Einzel lens faces upward, facing the source. In another embodiment, the SE detector is placed upstream of the Einzel lens, between the deflection system and the beam-limiting aperture. In yet another embodiment, a BSE detector is placed upstream of the Einzel lens, between the beam-limiting aperture and the deflection system, in addition to an SE detector upstream of the Einzel lens. In another embodiment, an SE extractor is placed at close-proximity to the sample surface.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 (prior art) illustrates a secondary electron detection system where the SE detector is placed downstream of the Einzel lens, between the Einzel lens and the sample.

Fig. 2 (prior art) illustrates a secondary electron detection system with increased spacing s and working space w .

Fig. 3 illustrates a secondary electron detection system where the SE detector is placed upstream of the Einzel lens and between the Einzel lens and the deflection plate.

Fig. 4 illustrates a secondary electron detection system where the SE detector is placed upstream of the Einzel lens and between the Einzel lens and the suppressor plate.

Fig. 5 illustrates a secondary electron detection system where the SE detector is placed upstream of the Einzel lens, between the Einzel lens and the beam-limiting aperture.

Fig. 6 illustrates a BSE detector placed upstream of the Einzel lens, between the beam-limiting aperture and the deflection system.

Fig. 7 illustrates a SE extractor placed between the sample and the Einzel lens.

DETAILED DESCRIPTION

Fig. 3 shows a secondary electron detection configuration located upstream of the Einzel lens (with respect to the electron beam) for microcolumn 300. It is understood that microcolumn 300 described hereto also includes a conventional

support housing structure (not shown) to support and enclose the components shown in Fig. 3. Sample 360 is held by stationary support 365 which is also a part of the microcolumn structure.

SE detector 350 is located at a distance d above the first electrode of objective lens 330. Placing SE detector 350 at a distance above the objective lens differs from the conventional microcolumn where the detector is located between the sample and the objective lens.

Objective lens 330 is typically, but not limited to, an electrostatic unipotential Einzel lens. Objective lens 330 can also be, for example, an immersion lens. When an immersion lens is used for objective lens 330, the last electrode of objective lens 330 is not at ground potential, but has a potential applied to it. As a result, an electric field exists between the last electrode of objective lens 330 and sample 360 which is normally grounded. The electric field between the last electrode and sample 360 is used to attract or to repel the secondary electrons emitted from sample 360. Sample 360 emits secondary electrons when an electron beam focused by objective lens 330 is directed onto sample 360. (The term "Einzel lens" and "objective lens" are used interchangeably in this disclosure.) Distance d is selected for optimum electron collection based on the particular Einzel lens design and working distance w .

Einzel lens 330 presents a very strong electron optical lens for the secondary electrons with energies of a few eV to tens of eV. Secondary electrons 380 are thereby strongly

focused, and exit Einzel lens 330 in a wide cone. A large fraction of the emitted secondary electrons 380 reaches the active area of SE detector 350. With this configuration, only those secondary electrons emitted at very small angles are not captured. Hence, the detector efficiency is improved and yields a better signal-to-noise ratio. Further improvement can be achieved by applying a small bias voltage to the detector surface, which attracts secondary electrons that would otherwise miss secondary electron detector 350.

For example, for a working distance $w = 0.5 - 1$ mm, and detector distance $d = 0.75$ mm, secondary electrons 380 emitted at angles larger than $15-20^\circ$ reach SE detector 350, yielding a detector efficiency of more than 80%.

SE detector 350 can be of a single or double stage microchannel plate (MCP) detector which is a conventional and commercially available high gain, low noise, continuous dynode type electron multiplier. The high gain $10^4 - 10^8$, is obtained at an operating voltage of 1000 - 3000 V for single or double stage MCP detectors, respectively. The high intrinsic gain of the detector allows the use for signal processing. In addition, the MCP detector consists of two pieces: the MCP, and the anode-collector electrodes that are machined out of an insulator, for example, Macor or other ceramic, with a patterned electrode thereon made by metal vacuum deposition and electroplating. Thereby the whole detector assembly, operating at 1000 V between the input and output side of the MCP, is only 0.8 mm high. SE

detector 350 can also be, but not limited to, a conventional p-i-n or Schottky diode type solid-state detector, an Everhart-Thornley scintillator/photomultiplier combination or a channeltron electron multiplier.

At larger working distances w , some of the secondary electrons emitted at larger angles may be obstructed by the inner bore of Einzel lens 330 electrodes. A suitable increase of Einzel lens 330 bore diameters can recover the secondary electrons which would be lost otherwise.

Furthermore, because an increase in the distance between sample 360 and SE detector 350 does not involve a respective increase in working distance w and the relatively thick SE detector 350 is not occupying the space between Einzel lens 330 and sample 360, working distance w can be minimized, e.g. to below 0.5 mm. Because aberrations decrease when working distance w is reduced, the spatial resolution can be further improved by using the upstream of the Einzel lens configuration.

Fig. 4 shows an alternate configuration for Fig. 3. SE detector 450 is again located between Einzel lens 430 and deflection plate 420. However, in this configuration, SE detector 450 is placed immediately above the first electrode of Einzel lens 430 with shield 440 facing upward toward the source. A suppressor plate 490 is placed at a distance d above SE detector 450 to bend the secondary electrons backward toward SE detector 450.

The configuration shown in Fig. 4 provides the advantage of higher detection efficiency of near-axis secondary electrons because suppressor plate 490 bends the near-axis secondary electrons backward such that they arrive at SE detector 450 with a wider distribution.

Fig. 5 shows a different configuration for a secondary electron detection system, again with the detector upstream of the Einzel lens. Here, SE detector 550 is located at a distance b above deflection plate 520 which is a few mm above the first electrode of Einzel lens 530. Distance b is selected for optimum electron collection based on the particular Einzel lens design and working distance w .

Similar to the previous configuration, secondary electrons 480 are strongly focused and exit Einzel lens 530 in a wide cone. Secondary electrons 580 then pass through deflection plates 520. A large fraction of the emitted secondary electrons 580 reaches the active area of secondary electron detector 550, and only secondary electrons emitted at very small angles are not captured. Therefore, the detector efficiency is improved and yields a better signal-to-noise ratio.

The configuration shown in Fig. 5 is advantageous for obtaining large fields of view, since it allows decrease of the driving voltage of deflection plate 520 for a given field of view.

Fig. 6 shows another configuration for detecting both secondary and backscattered electrons. Secondary electrons are

detected in a similar manner as discussed above for Fig. 3. Backscattered electrons 680 are emitted from the surface of sample 660 with a cosine distribution in a wide cone at an energy near or equal to the primary electron 670 energy. Einzel lens 630 focuses backscattered electrons 680 near the plane from where primary electrons 670 are emitted. However, backscattered electrons 680 are emitted at a much wider angle. Backscattered electrons 680 which are emitted at an angle larger than the convergence angle of the primary electrons (about 0.5°), can be captured by BSE detector 690 located below beam-limiting aperture 610. If the inner bore diameter of BSE detector 690 is small enough, i.e. a few micrometers in diameter, a majority of the backscattered electrons are detected in this configuration.

A surface sensitive detector, such as, but not limited to, a metal-semiconductor-metal (MSM) detector, a delta-doped detector or a P-N junction detector, may be incorporated into beam-limiting aperture 610. MSM detectors have the advantage of being easier to integrate with Einzel lens fabrication. In the microcolumn, MSM detectors can be used for BSE detection only with a gain in the range of 200 - 1000.

The detector being upstream of Einzel lens configuration has the advantage of capturing a large portion of secondary electrons from a relatively flat surface. However, for deep holes or trenches, secondary electrons emitted at the bottom may get absorbed by the sidewalls. To assist the escape of secondary electrons from such holes or trenches, an

electrostatic field at the surface of the sample is needed. The electrostatic field can be achieved, for example, using the objective lens in the immersion lens mode as described earlier. However, the approach using the objective lens in the immersion lens mode has the undesirable effect of turning the sample into an element of the objective lens. Thus, any surface imperfection or local surface potential that may exist on the sample surface may deteriorate spatial resolution.

To minimize the effect of a surface imperfection or local surface potential on the sample surface, a secondary electron (SE) extractor 735 in the form of a thin plate is placed at close-proximity to the sample surface, as shown in Fig. 7. SE extractor 735 contains a round hole with a diameter d_{ext} . The round hole in SE extractor 735 is aligned to the column axis. The size of the hole should only be large enough to allow the primary beam to scan sample 760 and for the SE to escape from sample 760 for detection upstream. For microcolumn, d_{ext} is typically 50 to 100 μm .

By applying a voltage V_{ext} , to SE extractor 735, an extraction field is created at sample 760 to assist the escape of electrons from deep holes and trenches. A field-free region is created between objective lens 730 and SE extractor 735 when the same potential, V_{ext} , is applied to the last electrode of objective lens 730. By using the configuration shown in Fig. 7, any surface imperfections and local potentials on sample 760 are effectively screened-off from objective lens 730 focusing

actions, thereby suppressing sample effect on the spatial resolution.

Although the invention has been described with reference to particular embodiments, the description is only an example of the invention's application and should not be taken as a limitation. Various other adaptations and combinations of features of the embodiments disclosed are within the scope of the invention as defined by the following claims.

CLAIMS

We claim:

1. A microcolumn, comprising:
an electron source;
an electrostatic objective lens located downstream of the electron source with respect to an electron beam emitted from the electron source;
a deflection plate located to deflect the electron beam;
and
a secondary electron detector located upstream of the objective lens with respect to the electron beam.
2. The microcolumn of Claim 1, wherein said objective lens is an unipotential Einzel lens.
3. The microcolumn of Claim 1, wherein said objective lens is an immersion lens.
4. The microcolumn of Claim 1, wherein said secondary electron detector includes a shield.
5. The microcolumn of Claim 4, wherein said secondary electron detector and shield face downward toward a target of said electron beam.

6. The microcolumn of Claim 4, wherein said secondary electron detector and shield face upward toward said electron source.

7. The microcolumn of Claim 1, wherein said secondary electron detector is a microchannel plate detector.

8. The microcolumn of Claim 7, wherein said microchannel plate detector is a single stage microchannel plate detector.

9. The microcolumn of Claim 7, wherein said microchannel plate detector is a double stage microchannel plate detector.

10. The microcolumn of Claim 1, wherein said secondary electron detector is disposed between said objective lens and said deflection plate.

11. The microcolumn of Claim 1, further comprises a suppressor plate located to bend a secondary electron backward toward said secondary electron detector.

12. The microcolumn of Claim 11, wherein said secondary electron detector is disposed between said objective lens and said suppressor plate.

13. The microcolumn of Claim 12, wherein said secondary electron detector includes a shield, said secondary electron detector and shield facing upward toward said electron source.

14. The microcolumn of Claim 1, wherein said secondary electron detector is disposed between a limiting aperture and said deflection plate.

15. The microcolumn of Claim 1, further comprising a backscatter electron detector located upstream of the objective lens.

16. The microcolumn of Claim 15 wherein said backscatter electron detector is located between a limiting aperture and said deflection plate.

17. The microcolumn of Claim 16, wherein said backscatter electron detector is incorporated into said limiting aperture.

18. The microcolumn of Claim 17, wherein said backscatter electron detector is a surface sensitive detector.

19. The microcolumn of Claim 18, wherein said surface sensitive detector is a metal-semiconductor-metal detector.

20. The microcolumn of Claim 18, wherein said surface sensitive detector is a delta-doped detector.

21. The microcolumn of Claim 1, further comprising a support for a target of said electron beam.

22. The microcolumn of Claim 1, further comprising a secondary electron extractor disposed between said objective lens and a target of said electron beam.

23. A method for detecting secondary electrons in a microcolumn having an objective lens, comprising:

directing an electron beam focused by said objective lens onto a sample, said sample thereby emitting a plurality of secondary electrons and a plurality of backscatter electrons from said electron beam; and

detecting said secondary electrons at a location upstream of said objective lens with respect to said electron beam.

24. The method of Claim 23, further comprising deflecting said electron beam.

25. The method of Claim 24, wherein detecting said secondary electrons comprises detecting at a location between said objective lens and where said deflecting occurs.

26. The method of Claim 25, further comprising limiting a width of said electron beam.

27. The method of Claim 26, further comprising detecting backscatter electrons at a location between a location at which said limiting and said deflecting occur.

28. The method of Claim 23, further comprising limiting a width of said electron beam.

29. The method of Claim 28, further comprising deflecting said electron beam.

30. The method of Claim 29, wherein detecting said secondary electrons comprising detecting at a location between a location at which said limiting and said deflecting occur.

31. The method of Claim 29, further comprising detecting backscatter electrons at a location between a location at which said limiting and said deflecting occur.

32. The method of Claim 23, further comprising applying a bias voltage to said objective lens.

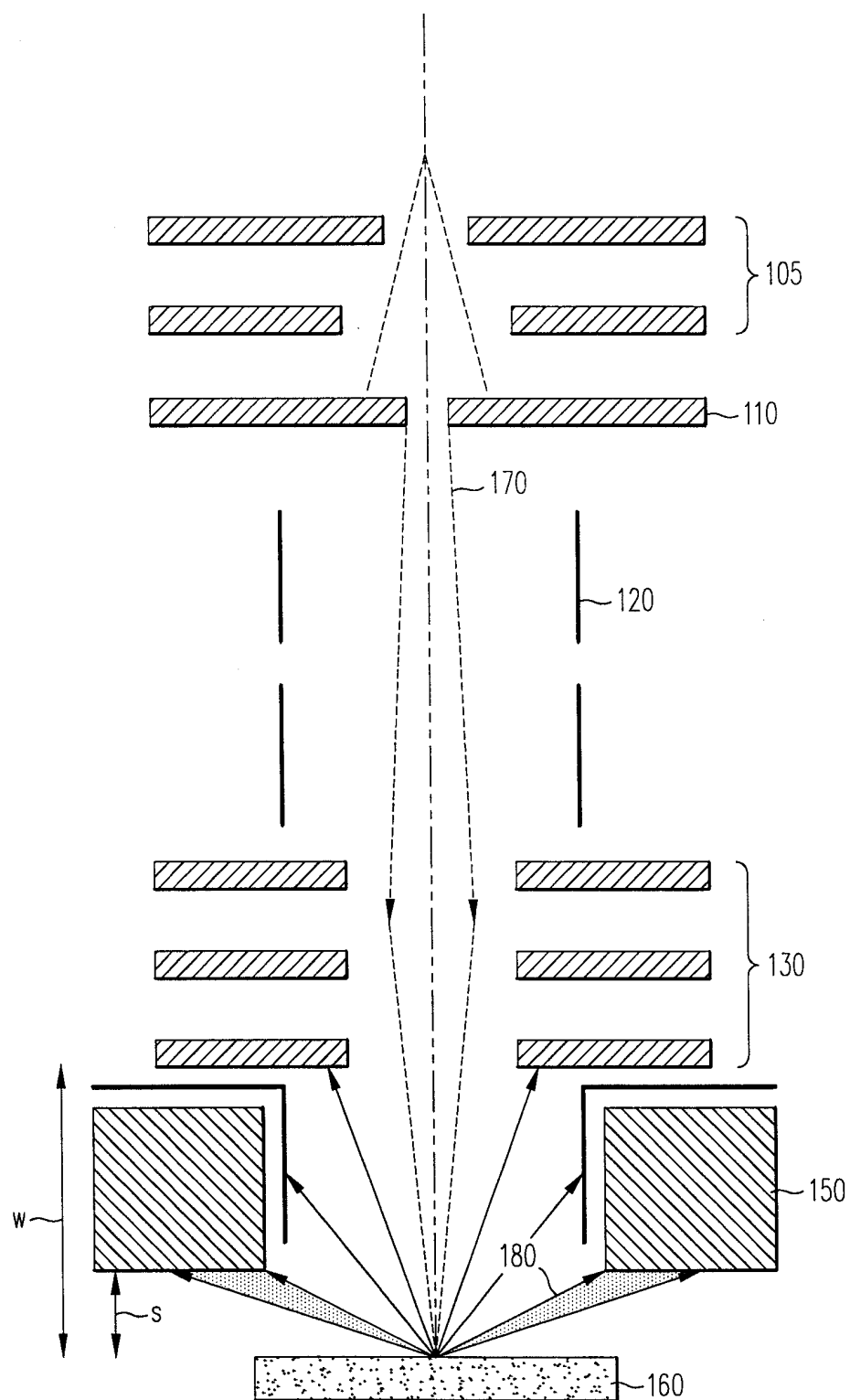
33. The method of Claim 23, further comprising bending said secondary electrons toward said location.

34. The method of Claim 23, further comprising:
placing a secondary electron extractor between said
objective lens and said sample; and
creating a field-free region between said objective lens
and said secondary electron extractor.

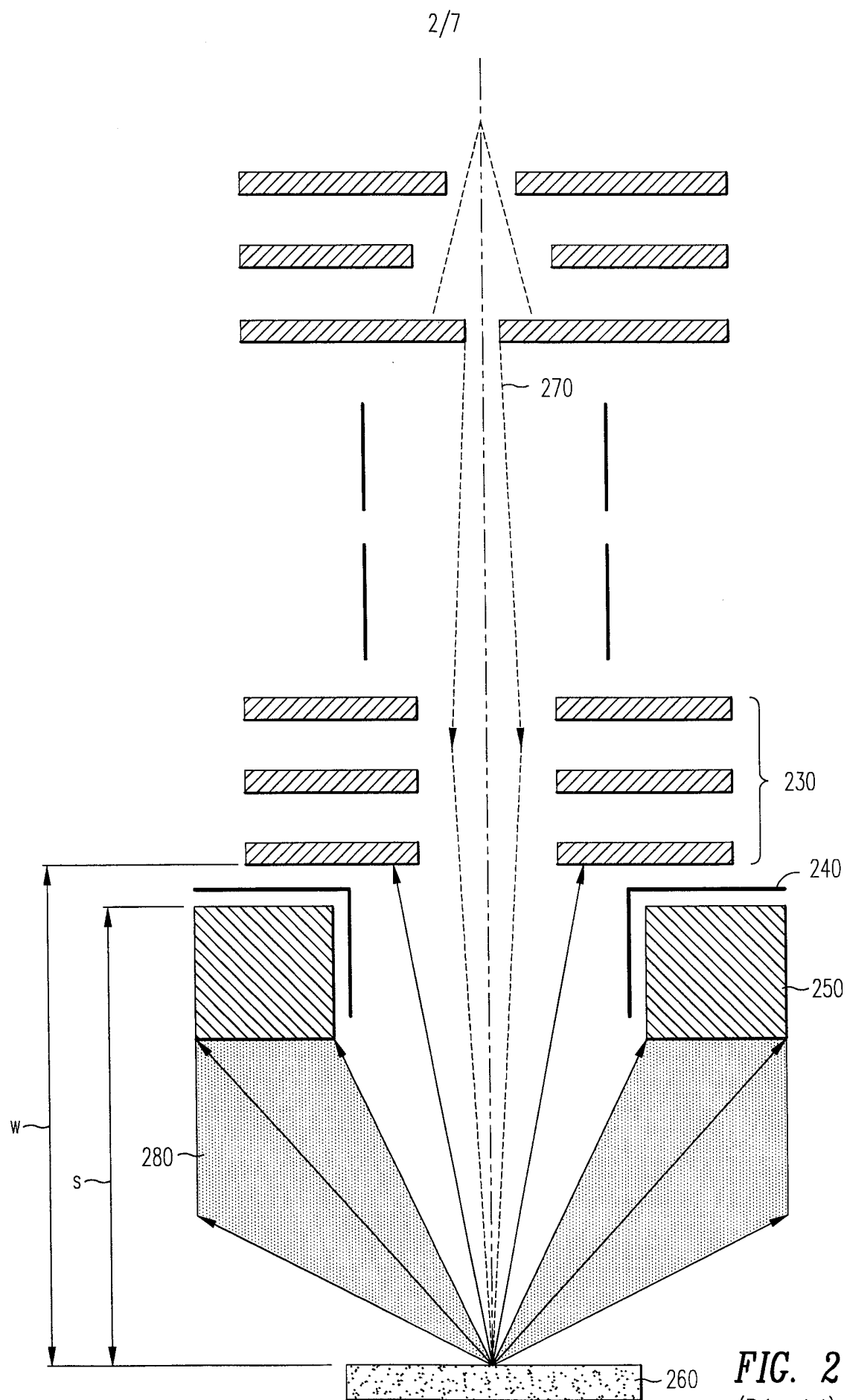
35. The method of Claim 34, wherein said creating a field-free region further comprising:
creating an extraction field at said sample by applying
first voltage to said extractor; and
applying second voltage to a last electrode of said
objective lens.

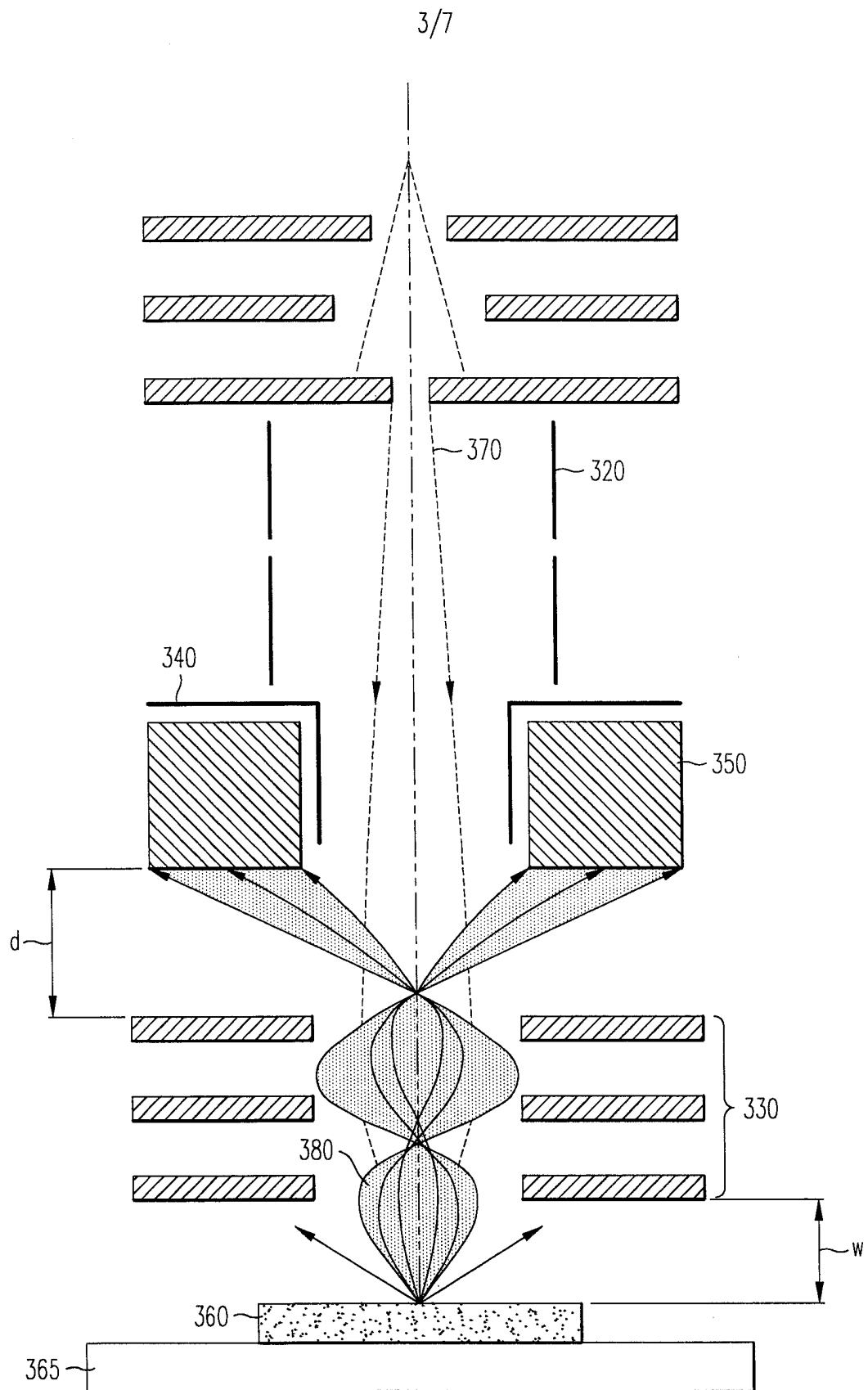
36. The method of Claim 35, wherein said first voltage
equals said second voltage.

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**FIG. 1**

(Prior Art)



*FIG. 3*

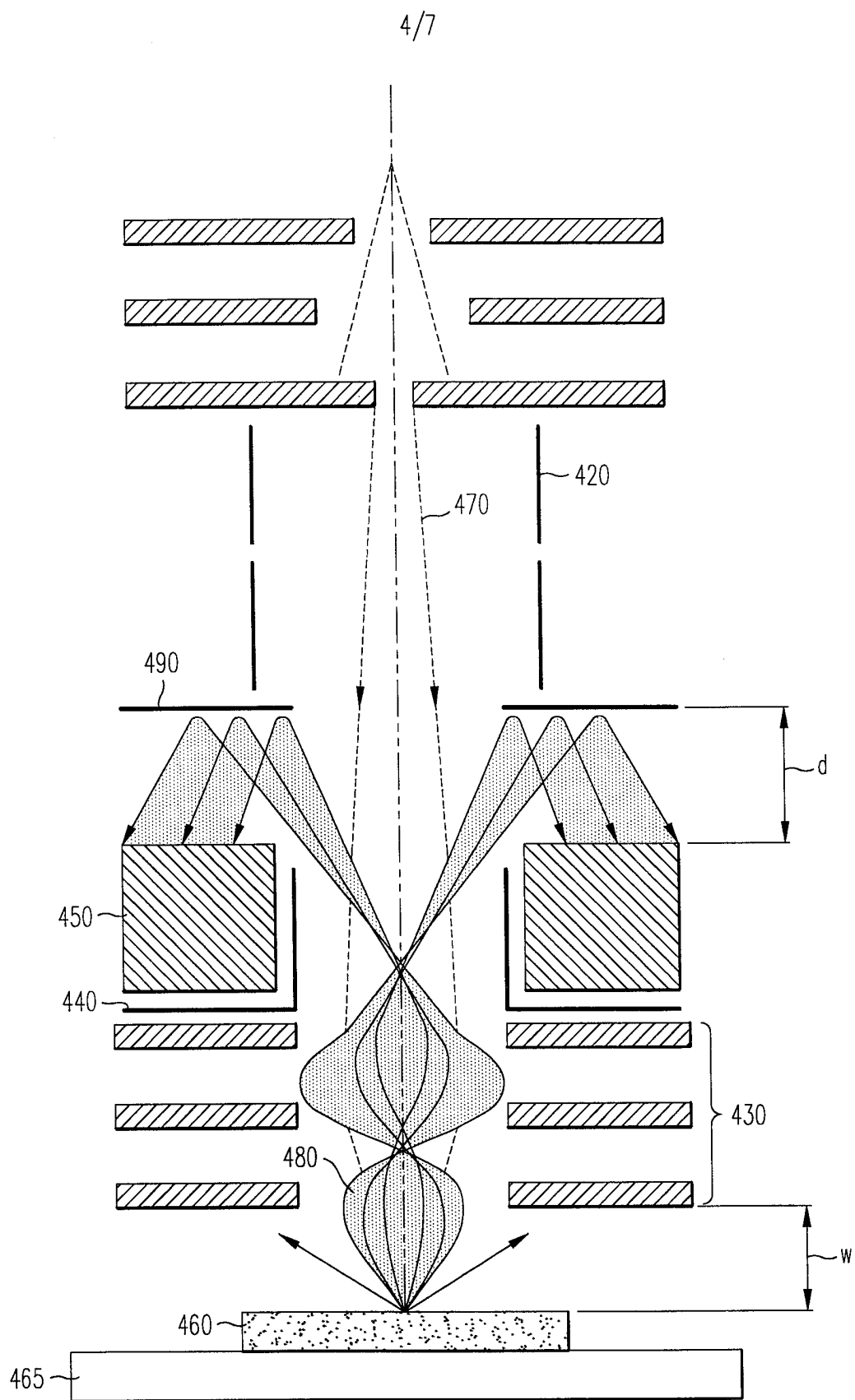


FIG. 4

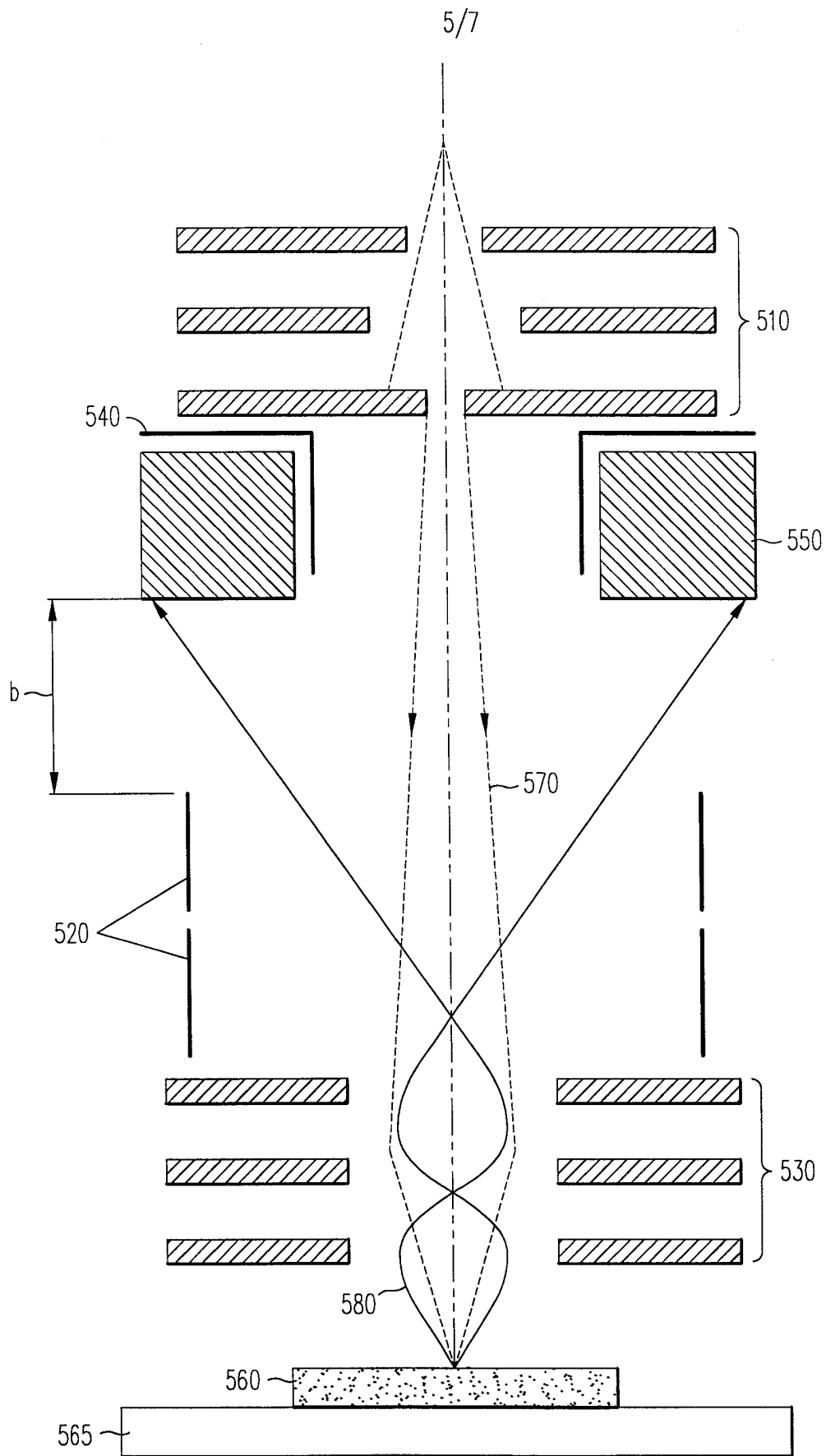


FIG. 5

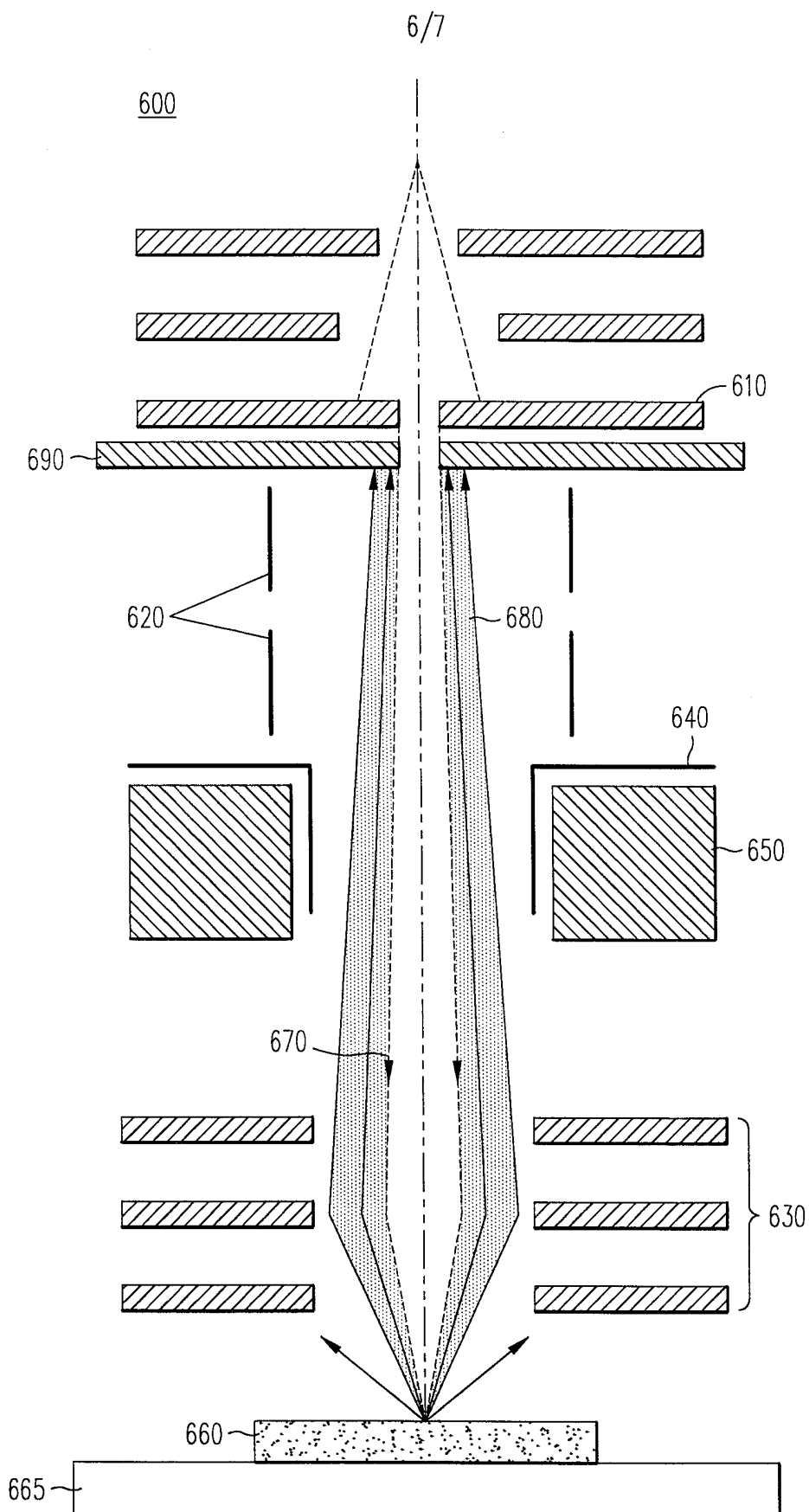
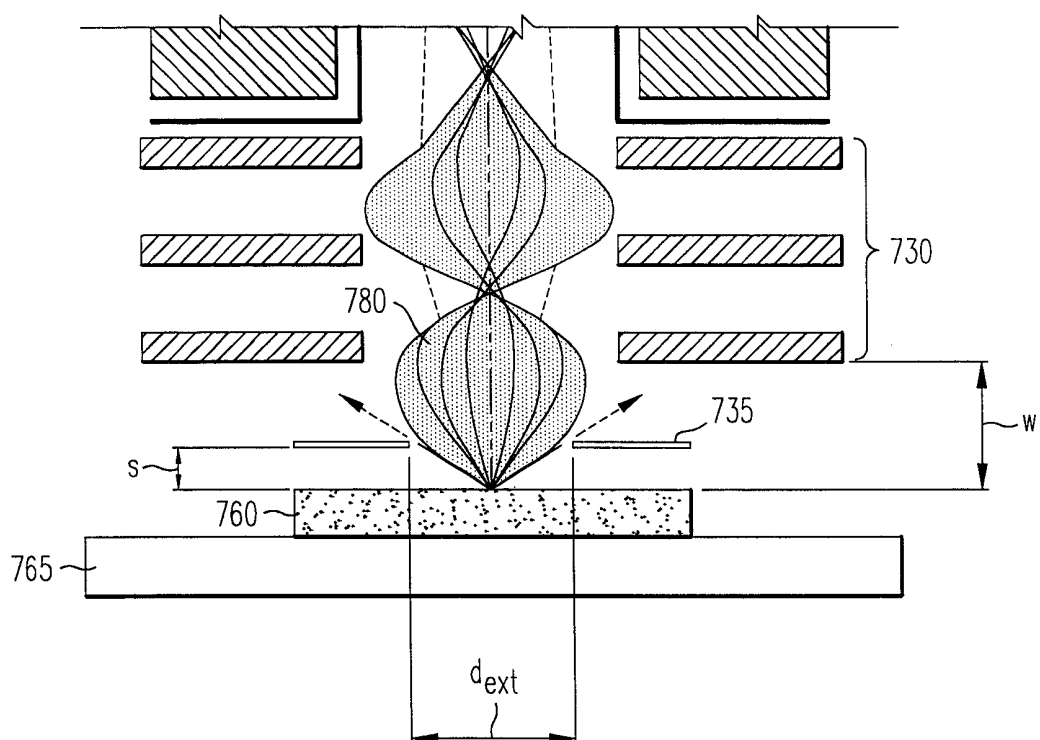


FIG. 6

**FIG. 7**