

US00RE43757E

(19) **United States**
(12) **Reissued Patent**
Liu et al.

(10) **Patent Number:** **US RE43,757 E**
(45) **Date of Reissued Patent:** ***Oct. 23, 2012**

(54) **ROTATIONAL STAGE FOR HIGH SPEED, LARGE AREA SCANNING IN FOCUSED BEAM SYSTEMS**

(75) Inventors: **Yong Yu Liu**, Sanchong (TW); **Daniel S. H. Chan**, Singapore (SG); **Jacob C. H. Phang**, Singapore (SG)

(73) Assignee: **National University of Singapore**, Singapore (SG)

(*) Notice: This patent is subject to a terminal disclaimer.

(21) Appl. No.: **11/824,466**

(22) Filed: **Jun. 28, 2007**

Related U.S. Patent Documents

Reissue of:

(64) Patent No.: **6,911,656**
Issued: **Jun. 28, 2005**
Appl. No.: **10/884,698**
Filed: **Jul. 1, 2004**

U.S. Applications:

(63) Continuation of application No. 10/245,865, filed on Sep. 16, 2002, now Pat. No. 6,777,688.

(51) **Int. Cl.**
H01J 37/20 (2006.01)
H01J 37/00 (2006.01)

(52) **U.S. Cl.** **250/442.11**; 250/306; 250/307; 250/309; 250/310; 250/311; 250/440.11; 250/441.11; 250/492.1; 250/492.2; 250/492.3; 250/492.21; 250/492.22

(58) **Field of Classification Search** 250/306, 250/307, 309-311, 440.11, 441.11, 443.11, 250/492.1, 492, 2, 492.3, 492.21, 492.22, 250/492.23

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,670,153	A *	6/1972	Rempert et al.	250/200
3,919,558	A	11/1975	Brouillette et al.	
4,376,891	A *	3/1983	Rauscher et al.	250/307
5,390,112	A *	2/1995	Tam	378/17
5,868,952	A *	2/1999	Hatakeyama et al.	216/66
5,868,953	A *	2/1999	Maekawa et al.	216/89
5,888,682	A	3/1999	Nakasuji	
5,986,765	A	11/1999	Nakasuji	
5,986,795	A	11/1999	Nakasuji	356/399

(Continued)

OTHER PUBLICATIONS

Office action mailed Feb. 26, 2003, for U.S. Appl. No. 10/245,865.

(Continued)

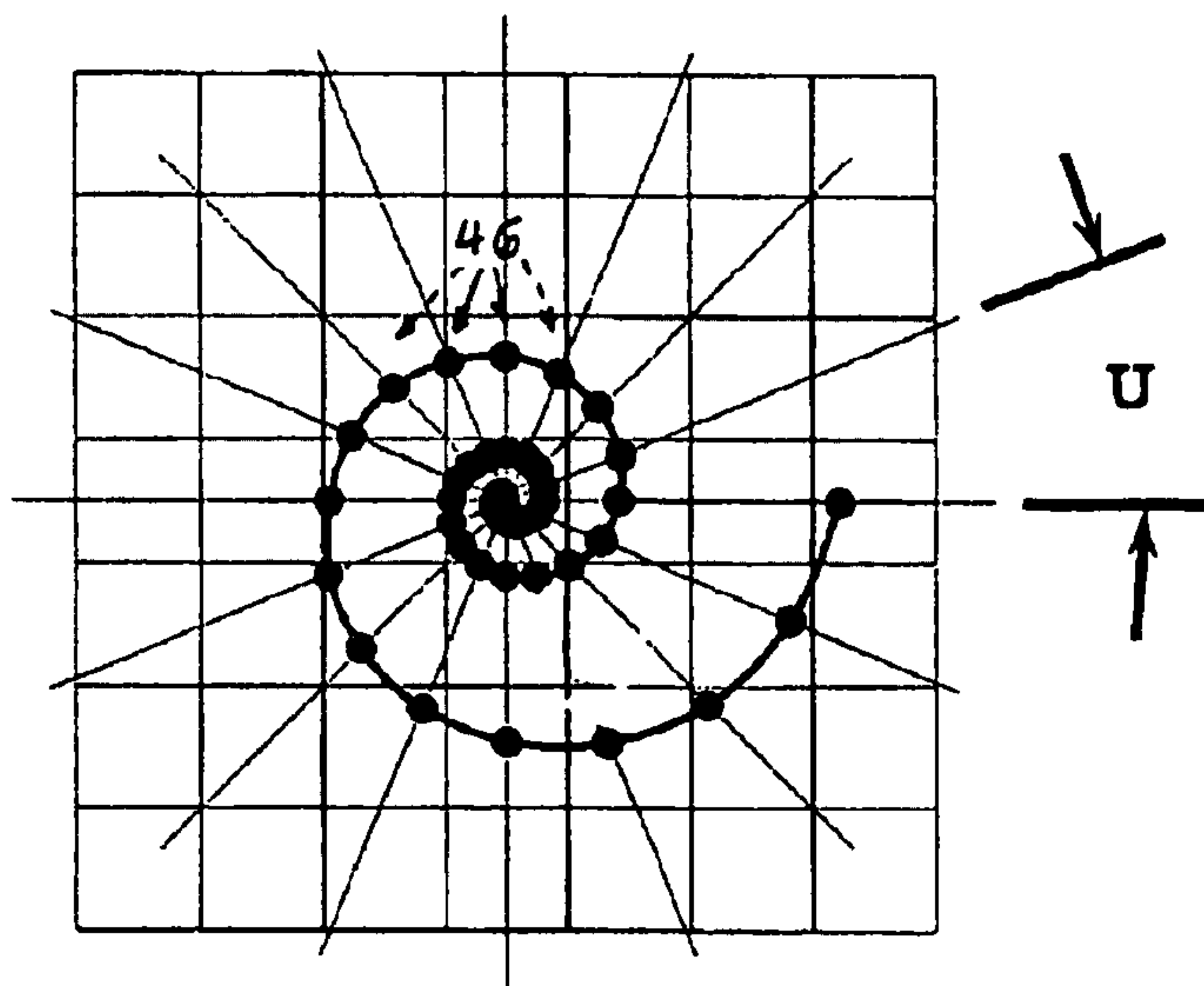
Primary Examiner — Bernard E Souw

(74) *Attorney, Agent, or Firm* — Schwabe, Williamson & Wyatt, P.C.

(57) **ABSTRACT**

A mechanical scanning stage for high speed image acquisition in a focused beam system. The mechanical scanning stage preferably is a combination of four stages. A first stage provides linear motion. A second stage, above the first stage, provides rotational positioning. A third stage above the rotational stage is moveable in a first linear direction, and the fourth stage above the third stage is positionable in a second linear direction orthogonal to the first direction. The four stages are responsive to input from a controller programmed with a polar coordinate pixel addressing method, for positioning a specimen mounted on the mechanical stage to allow an applied static focus beam to irradiate selected areas of interest, thereby imaged by collecting signals from the specimen using a polar coordinate pixel addressing method.

21 Claims, 2 Drawing Sheets



US RE43,757 E

Page 2

U.S. PATENT DOCUMENTS

6,015,976 A * 1/2000 Hatakeyama et al. ... 250/492.23
6,185,271 B1 * 2/2001 Kinsinger 378/19
6,444,991 B1 * 9/2002 Yamada et al. 250/442.11
6,683,316 B2 * 1/2004 Schamber et al. 250/492.1
6,777,688 B2 * 8/2004 Liu et al. 250/442.11
6,911,656 B2 * 6/2005 Liu et al. 250/442.11
7,923,702 B2 * 4/2011 Buhler et al. 250/440.11
2002/0175295 A1 11/2002 Gordon et al.
2002/0186632 A1 * 12/2002 Kumasaka et al. 369/47.49
2008/0317321 A1 * 12/2008 Zhang et al. 382/132
2012/0025075 A1 * 2/2012 Moore et al. 250/307

OTHER PUBLICATIONS

Final Office action mailed Aug. 13, 2003, for U.S. Appl. No. 10/245,865.

Notice of Allowance mailed May 5, 2004, for U.S. Appl. No. 10/245,865.

Notice of Allowance mailed Feb. 15, 2005, for U.S. Appl. No. 10/884,698.

* cited by examiner

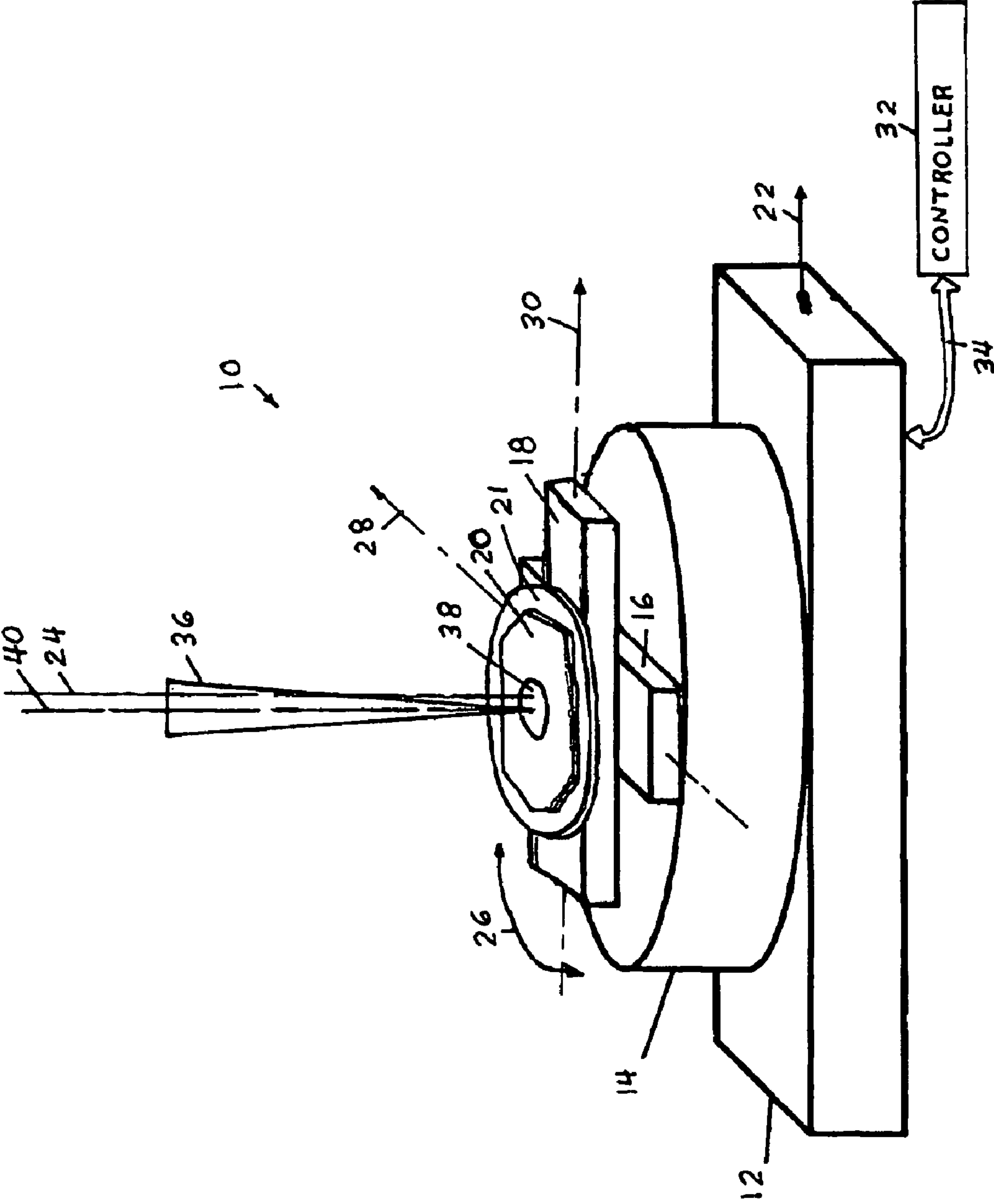


FIG. 1

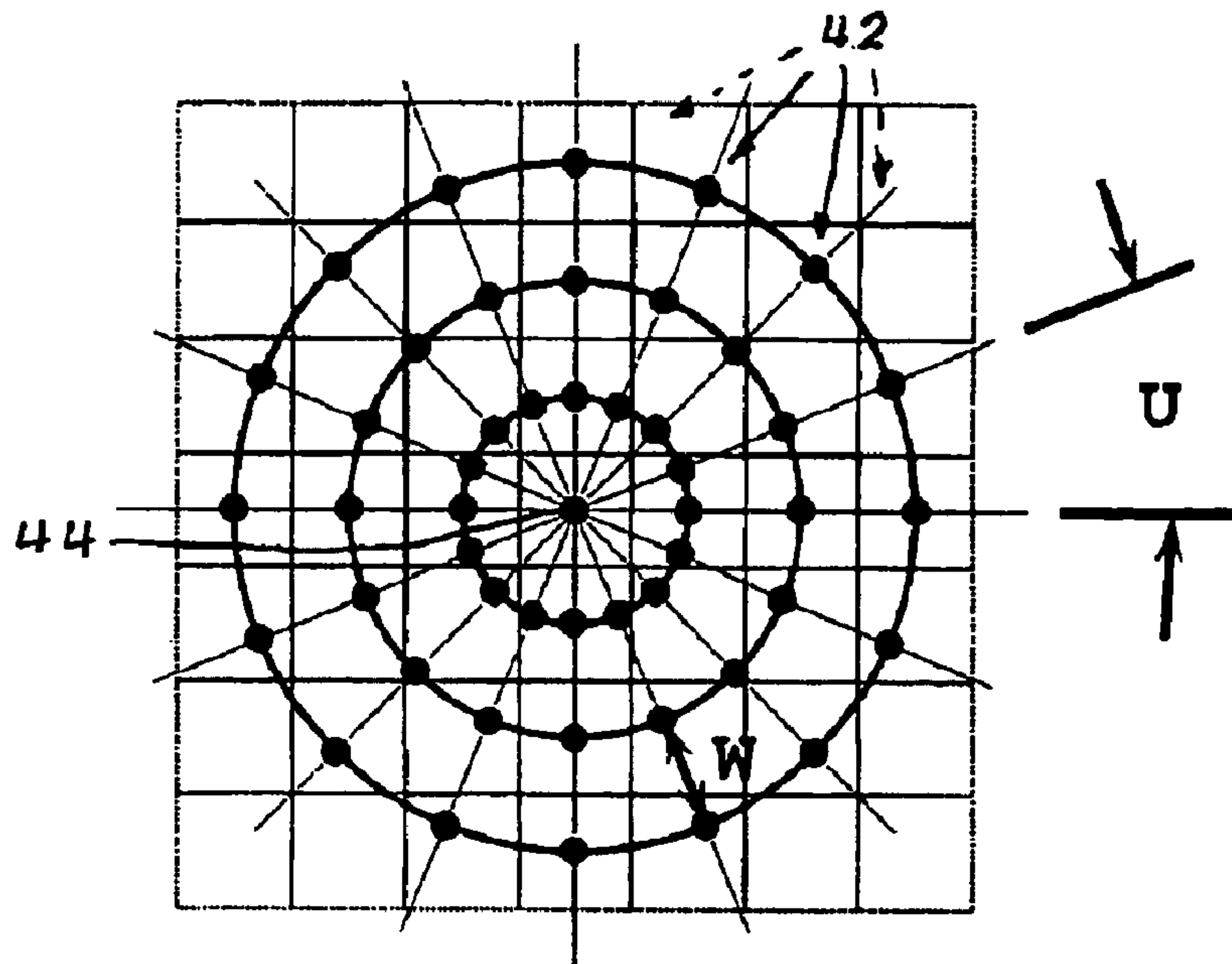


FIG 2

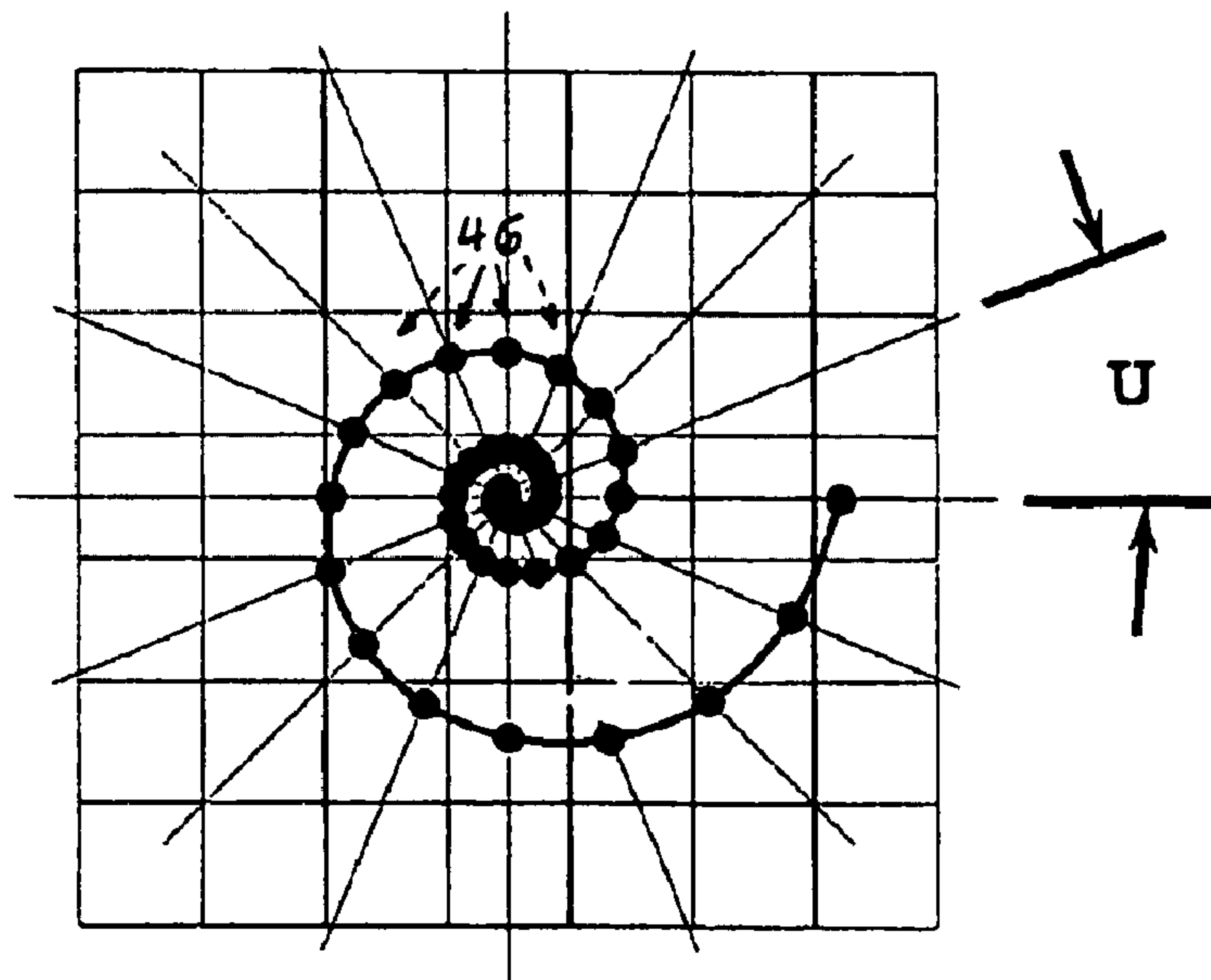


FIG 3

**ROTATIONAL STAGE FOR HIGH SPEED,
LARGE AREA SCANNING IN FOCUSED
BEAM SYSTEMS**

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

CROSS REFERENCE TO RELATED APPLICATION

[This] *The present application is a reissue application of U.S. Pat. No. 6,911,656, issued on Jun. 28, 2005 and filed as U.S. patent application Ser. No. 10/884,698 on Jul. 1, 2004, and entitled "Rotational Stage for High Speed Large Area Scanning in Focused Beam Systems", which is a continuation of [U.S. Pat. Ser. No. 10/245,865 filed on Sep. 16, 2002 now] U.S. Pat. No. 6,777,688, issued on Aug. 17, 2004 and filed as U.S. patent application Ser. No. 10/245,865 on Sep. 16, 2002, the disclosures of which are incorporated by reference in their entirety.*

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to moveable stages for use in focused beam systems; and more particularly to a high speed rotational stage in conjunction with a linear stage to form a high speed scanning system without scanning the beam, allowing a large area specimen to be imaged with a substantially higher speed using an optimally focused beam.

2. Description of the Prior Art

In the context of scanning microscopy, the most common image formation systems in the prior art make use of Cartesian raster scanning to form an image. In a typical imaging system, a source of energy such as an electron beam, ion beam or photon beam is used to irradiate a specimen. The interaction between the source beam and the specimen produces a signal that can be detected which corresponds to the signal intensity at the interaction point. There are two Cartesian raster scanning mechanisms commonly used to form an image: (1) a beam scanning system wherein the source beam is Cartesian raster scanned over the area of interest of a static specimen; (2) a stage scanning system wherein the specimen is mounted on a mechanical Cartesian scanning stage, and the stage is scanned with respect to the static source beam to cover the area of interest.

In a beam scanning system, the source beam is typically scanned from left to right in a raster manner, pixel by pixel, before 'flying back' to the beginning of the next line. This process repeats from the top to the bottom for a complete image acquisition before returning to the top of the scan again. In a stage scanning system, the mechanical scanning stages scan from left to right in a raster manner using stepper motors, servo motors or voice coils. These two methods impose significant problems and limitations. Firstly, both methods need a fly-back at the end of each line scan, which slows down the image acquisition. For the stage scanning system, the relatively large mass of the mechanical stage needs significant settling time, which further slows down the rate of image acquisition. In addition to this, the beam scanning system suffers from aberrations when the beam is deflected from the optical axis while scanning a relatively large area. This is a serious drawback of the beam scanning system when scanning a large area.

In conclusion, a mechanical scanning stage with high speed capability for large area specimen scanning would have advantages in many applications.

SUMMARY OF INVENTION

It is, therefore, an object of the present invention to provide a mechanical scanning stage for high speed image acquisition in a focused beam system.

It is another object of the present invention to provide a mechanical scanning stage that can achieve high speed image acquisition of a large area specimen.

Briefly, a preferred embodiment of the present invention includes a mechanical scanning stage for high speed image acquisition in a focused beam system. The mechanical scanning stage preferably is a combination of four stages. A first stage provides linear motion. A second stage, above the first stage, provides rotational positioning. A third stage above the rotational stage is moveable in a first linear direction, and the fourth stage above the third stage is positionable in a second linear direction orthogonal to the first direction. The four stages are responsive to input from a controller programmed with a polar coordinate pixel addressing method, for positioning a specimen mounted on the mechanical stage to allow an applied static focus beam to irradiate selected areas of interest, thereby imaged by collecting signals from the specimen using a polar coordinate pixel addressing method.

IN THE DRAWING

FIG. 1 is a three dimensional view illustrating a preferred embodiment of the present invention;

FIG. 2 is a plot illustrating a typical scanning and acquisition pattern using a concentric circular polar coordinates addressing method as applied by the embodiment of FIG. 1; and

FIG. 3 is a plot illustrating a scanning and acquisition pattern using a spiral polar coordinates addressing method as applied by the embodiment of FIG. 1.

DESCRIPTION OF PREFERRED EMBODIMENT

Referring now to FIG. 1 of the drawing, a preferred embodiment of the present invention includes a mechanical scanning stage **10** constructed as a combination of four stages **12-18** for positioning a specimen **20**. The specimen **20** is placed on specimen mounting apparatus, such as a plate **21** attached to the uppermost stage, which as illustrated in FIG. 1 is stage **18**. The first stage **12** provides linear motion along a direction/axis **22**. The second stage **14** is configured to rotate the specimen **20** in its plane, around an axis **24** orthogonal to the specimen. This is indicated by rotational arrow **26**. The third stage **16**, also designated as a Y position stage, is for moving the specimen linearly in a first (Y) direction indicated by arrow **28**, and the fourth stage **18** (X positioning stage) provides linear motion in a second (X) direction **30**, orthogonal to the first (Y) direction **28**. All of the four stages **12-18** are configured to be responsive to direction from a controller **32**. Communication for direction of all four stages is symbolically illustrated by arrow/bus **34**. The actual connection/communication method can be either wired or wireless, which will be apparent to those skilled in the art.

The arrangement of the four stages in FIG. 1 is given to illustrate a particular embodiment of the present invention. Various alternate embodiments will be apparent to those skilled in the art upon reading the present disclosure, and these are to be included in the present invention. For example,

stages **12** and **14** can be reversed in their vertical placement in the stack of stages. As will be discussed in the following, a further alternate embodiment includes the third and fourth stages eliminated. A still further alternate embodiment is the elimination of either, but not both of the third and fourth stages. For example, placing a second linear stage such as the third stage immediately above the first stage, in an orthogonal arrangement followed by the rotational second stage, provides much of the flexibility of the four stages. These and other variations are to be included in the spirit of the present invention. In addition, the various stages can be stacked vertically in any order, and these variations are all included in the present invention.

As illustrated in FIG. 1, the specimen **20** to be observed is mounted on the stage **18**, or i.e. on a plate **21** attached to stage **18**, and a static source (energy) beam **36** is applied to form a focused spot **38** on the specimen **20**. The beam **36** can be any type of energy beam as required for the particular imaging operation. For example, it can be an electron beam, ion beam or photon beam. The axis of rotation **24** of the rotational stage **14** is preferably aligned with the optical axis **40** of the focused beam system at the beginning of a scanning procedure. Other starting points are also included as alternate embodiments of this invention.

An area of interest on the specimen **20** is moved to the static source beam **36** spot **38** by moving the X positioning stage **18** and the Y positioning stage **16**. The X and Y positioning stages **18** and **16** may be activated by wireless control or other means of remote activation, symbolically represented by controller **32** and arrow **34**. The scanning motion of the mechanical stage **10** includes rotational motion provided by the rotational stage **14** such that the specimen **20** rotates in the rotational direction **26**, and linear motion provided by the linear scanning stage **12**, scanning in the direction **22**. The rotational stage **14** may be rotated in the clockwise or counter clockwise direction. The source beam **36** remains stationary, directed along the axis **40**. The scanning operations are performed by the stage **10** elements **12-18**. As referred to above for one embodiment, the mechanical stage can be positioned initially so as to place the rotational axis **24** in alignment with the beam axis **40**. Starting in this position, a movement of the linear stage **12** one unit along the axis **22** moves the axis of rotation **24** of the rotational stage one unit away from the axis **40** of the beam **36**. As a result, the static source beam **36** can be activated to irradiate specimen areas along a circular path on the rotating specimen **20** as the rotational stage **14** is rotated. After the rotational stage **14** has rotated one revolution, the linear scanning stage **12** moves a pre-programmed distance, enabling the static source beam **36** to address areas on another concentric path as the stage **14** is rotated. As the linear scanning stage **12** moves further, the source beam **36** addresses a point further from the axis of rotation of the specimen stage **14**. This linear movement of the linear scanning stage **12** is preferably stopped when the source beam **36** reaches the edge of an area of interest on the specimen **20**. The linear movement may reverse its direction until the source beam **36** addresses the starting point again and vice versa. The above description details how image pixels corresponding to areas of interest on the specimen are addressed using concentric circular polar coordinates. This is further as depicted in FIG. 2. FIG. 2 illustrates a pattern of specimen areas shown as dots **42**, that are accessed by simply stepping the linear first stage **12** an increment/step equal to "W" from the center **44**, and the measurement of signal is acquired at time increments/steps "U" while the rotational stage **14** rotates at constant speed. When the stage **10** moves the specimen so as to posi-

tion a desired area **42** in line with the beam **36**, the beam is activated, and the measurement is acquired.

In the above described example of operation of the mechanical stage **10**, the third and fourth stages **16** and **18** are used to initially position the beam **36** at a required central location of an area of interest on the specimen. Subsequent to this positioning, the stages **16** and **18** preferably remain in a fixed position relative to the rotational stage axis **24**, serving no further purpose.

In another embodiment of operation of the mechanical stage **10**, the linear scanning stage **12** moves simultaneously and concurrently with the rotational stage **14**. The image pixels can then be addressed using spiral polar coordinates as depicted in FIG. 3. FIG. 3 illustrates areas on the specimen shown as dots **46**, wherein similar to the process described in reference to FIG. 2, the mechanical stage is directed by a controller to bring the desired areas **46** in line with the beam **36**. When an area **46** is in line with the beam, the beam source (not shown) is activated to apply the energy (beam), irradiating the area, resulting in the system acquiring the desired signal/measurement. The equipment for detecting and displaying such signals is well known to those skilled in the art, and need not be described herein in order for someone skilled in the art to reproduce the present invention.

Another embodiment of the mechanical stage **10** of the present invention includes only the linear stage **12** and rotational stage **14**, omitting the X and Y stages **16** and **18**. Operation in this embodiment requires manual alignment of a specimen orthogonal to the direction **22** of the linear stage **12**. The specimen is mounted on the upper stage, for example on the rotational stage **14** if the rotational stage is above the linear stage. The initial position of the specimen is then adjusted either manually, or manually and in combination with the linear stage **12**.

The apparatus of the present invention operated as described above, minimizes or eliminates linear stop and start motions, and totally avoids the settling down and "fly back" involved in the prior art line scanning systems which are responsible for the long image acquisition times of the prior art. The operation of the present invention illustrated in FIG. 3 and described above, eliminates all stop and start operations in image acquisition. The method described above employing concentric circles of acquisition as shown in FIG. 2, minimizes the magnitude of linear stop and start movements and avoids the prior art requirement of "fly back". In the method of FIG. 2, the source beam irradiates a full circular path after each unit movement of the linear scanning stage **12**, and the complete circular images require the linear scanning stage **12** to travel a total distance of only one half the image diameter. The static, non-moving, focused beam of the present invention avoids the problems associated with moving a beam. Prior art systems that required scanning the beam, for example, have an undesirable characteristic known as beam aberration. The apparatus of the present invention has the additional advantage of making it practical to scan a larger area of the specimen compared to a scanning beam system. In other words, the apparatus of the present invention can scan a large area without sacrificing image quality. This is not possible with a beam scanning system. Prior art mechanically scanned stages have the disadvantage of being very slow.

Although the present invention has been described above in terms of a specific embodiment, it is anticipated that alterations and modifications thereof will no doubt become apparent to those skilled in the art. It is therefore intended that the following claims be interpreted as covering all such alterations and modifications as fall within the true spirit and scope of the invention.

5

What is claimed is:

1. A method of scanning a specimen in an image acquisition system comprising:

- (a) placing a specimen on a mechanical stage for positioning and scanning said specimen for irradiation by an energy beam;
- (b) first moving said specimen along a first axis by a first stage of said mechanical stage providing linear positioning and scanning movement;
- (c) second moving said specimen by a second stage of said mechanical stage providing scanning rotational movement; and
- (d) impacting said specimen with a non-scanning energy beam, whereby the image is acquired during the scanning movements of the stages.

2. A method as recited in claim 1 further comprising directing movement of said mechanical stage by a controller.

3. A method as recited in claim 2 wherein said controller directs said scanning of said specimen by directing said first stage to sequentially position said specimen at each of a plurality of steps, and directs said second stage to sequentially rotate to a plurality of rotational positions for each said step.

4. A method as recited in claim 1 further comprising:

- (a) third moving said specimen by a third stage providing linear movement in an X direction; and
- (b) fourth moving said specimen by a fourth stage providing linear movement in a Y direction orthogonal to said X direction.

5. A method as recited in claim 4 wherein said third and fourth stages are for initial positioning of said specimen.

6. A method as recited in claim 1 further comprising third moving said specimen by a third stage providing linear movement orthogonal to said first axis.

7. A method as recited in claim 6 wherein said first stage is for scanning, and said third stage is for specimen positioning and is mounted on top of said second stage.

8. A method as recited in claim 7 wherein said second stage is mounted on top of said first stage.

9. A method as recited in claim 4 wherein said second stage is mounted on top of said first stage.

10. A method as recited in claim 1 further comprising programming a controller to direct movement of said first and second stages so as to cause said first stage to move simultaneously with said second stage.

11. A method as recited in claim 10 wherein said first and second stages are moved so as to address a location of interest on said specimen using spiral polar coordinates.

6

12. A method of scanning a specimen in an image acquisition system comprising:

moving said specimen along a first axis by a first stage of a mechanical stage providing linear positioning and scanning movement;

moving said specimen by a second stage of said mechanical stage providing scanning rotational movement; and impacting said specimen with a non-scanning energy beam, wherein the image is acquired during the scanning movements of the first and second stages.

13. The method as recited in claim 12 further comprising directing movement of said mechanical stage by a controller.

14. The method as recited in claim 12, and further comprising:

directing said scanning of said specimen by directing said first stage to sequentially position said specimen at each of a plurality of steps; and

directing said second stage to sequentially rotate to a plurality of rotational positions for each said step.

15. The method as recited in claim 12, and further comprising:

moving said specimen by a third stage providing linear movement in an X direction; and

moving said specimen by a fourth stage providing linear movement in a Y direction substantially orthogonal to said X direction.

16. The method as recited in claim 12, and further comprising moving said specimen by a third stage providing linear movement substantially orthogonal to said first axis.

17. The method as recited in claim 16, wherein said first stage is adapted for scanning, and said third stage is adapted for specimen positioning and is mounted on top of said second stage.

18. The method as recited in claim 17, wherein said second stage is mounted on top of said first stage.

19. A method as recited in claim 15 wherein said second stage is mounted on top of said first stage.

20. A method as recited in claim 12, and further comprising programming a controller to direct movement of said first and second stages so as to cause said first stage to move simultaneously with said second stage.

21. A method as recited in claim 20, wherein said first and second stages are moved so as to address a location of interest on said specimen using spiral polar coordinates.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : RE43,757 E
APPLICATION NO. : 11/824466
DATED : October 23, 2012
INVENTOR(S) : Liu et al.

Page 1 of 2

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Delete drawing sheet 2, and substitute the attached drawing sheet 2 therefor.

In Fig. 2, Sheet 2 of 2, delete "FIG" and insert -- FIG. --, therefor.

In Fig. 3, Sheet 2 of 2, delete "FIG" and insert -- FIG. --, therefor.

In Column 2, Line 29, delete "DRAWING" and insert -- DRAWINGS --, therefor.

In Column 6, Line 36, in Claim 19, delete "15" and insert -- 15, --, therefor.

Signed and Sealed this
Second Day of April, 2013



Teresa Stanek Rea
Acting Director of the United States Patent and Trademark Office

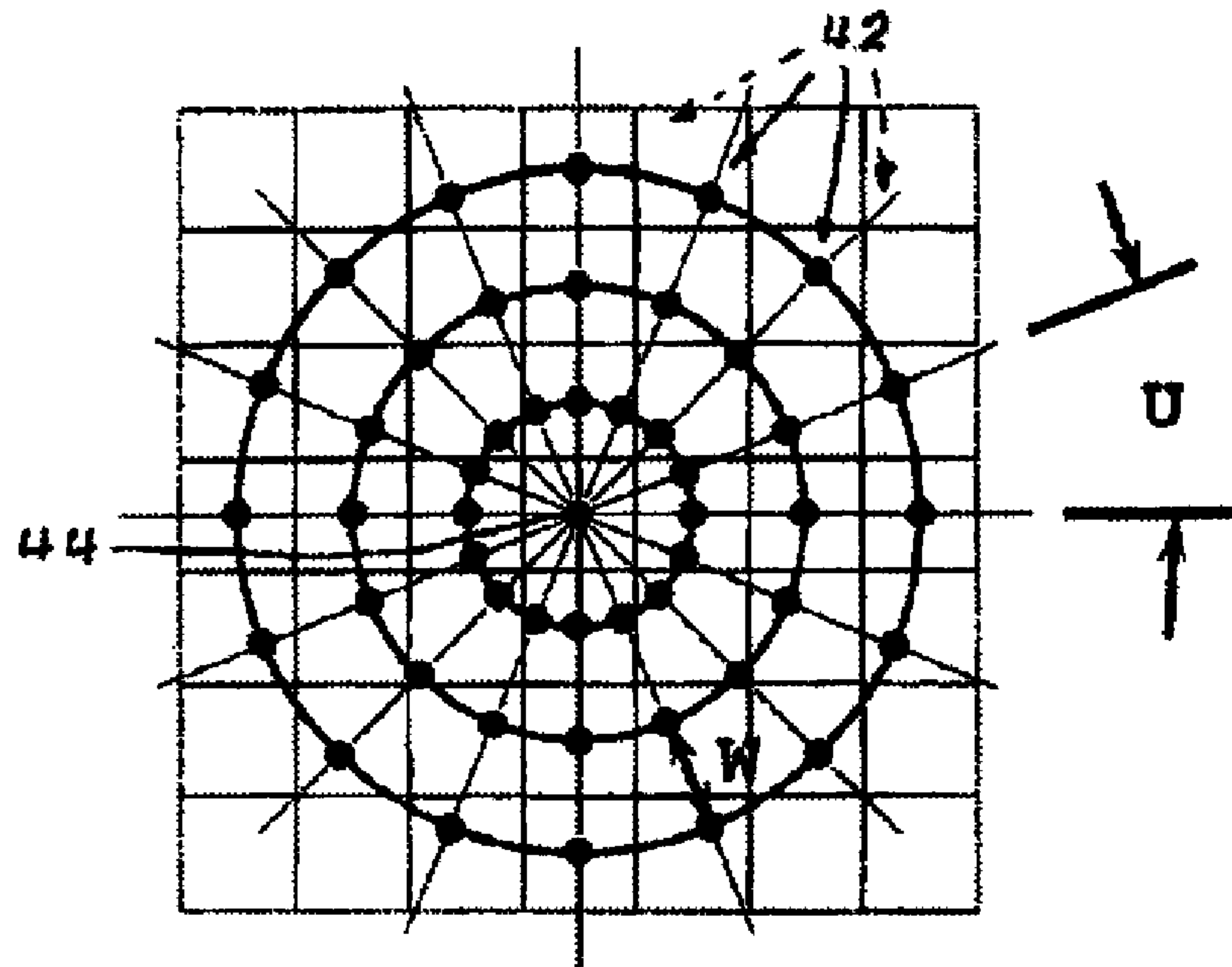


FIG. 2

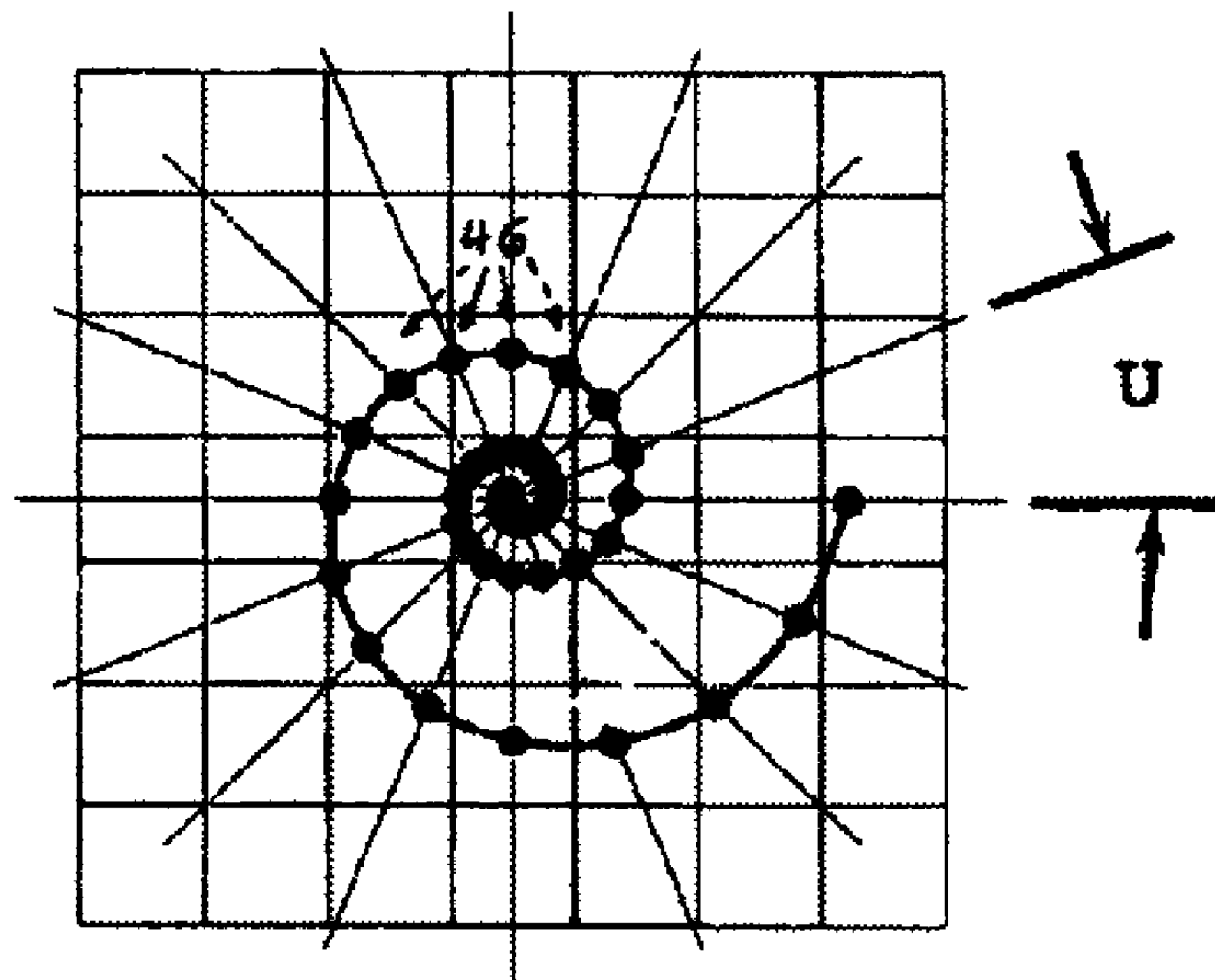


FIG. 3