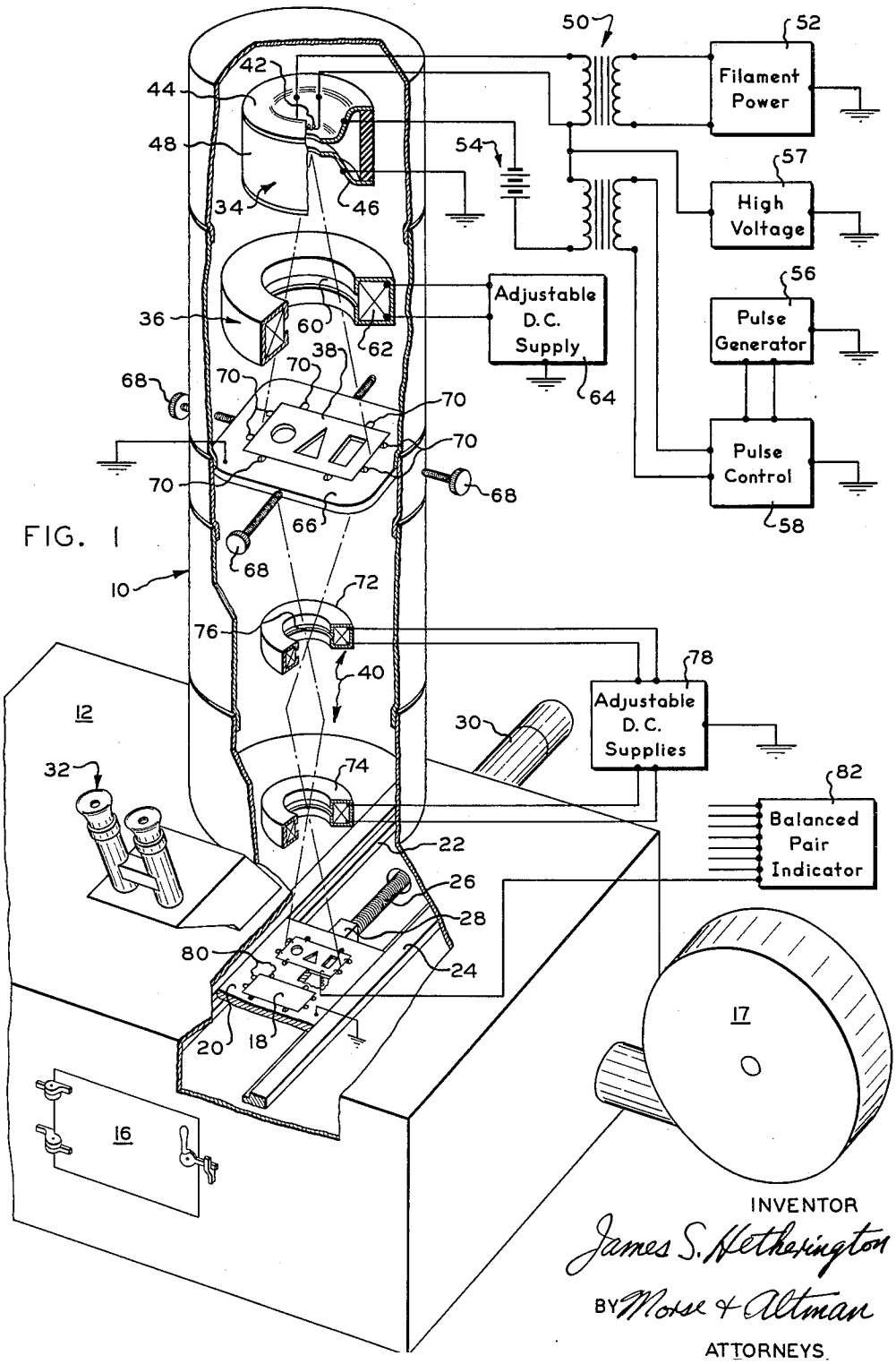
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ELECTRON BEAM DEVICES AND PROCESSES

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FIG. 1



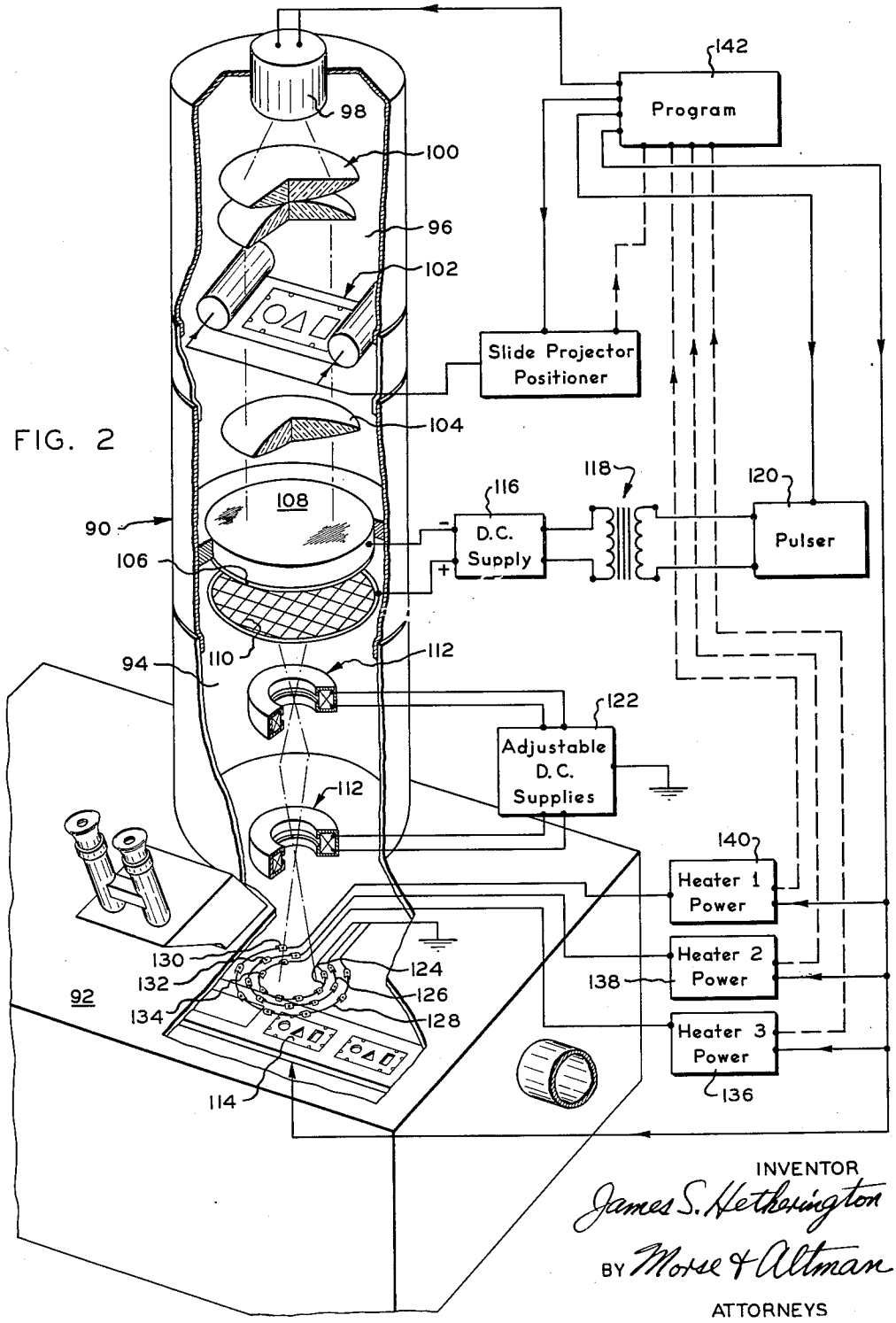
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ELECTRON BEAM DEVICES AND PROCESSES

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FIG. 2



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FIG. 3

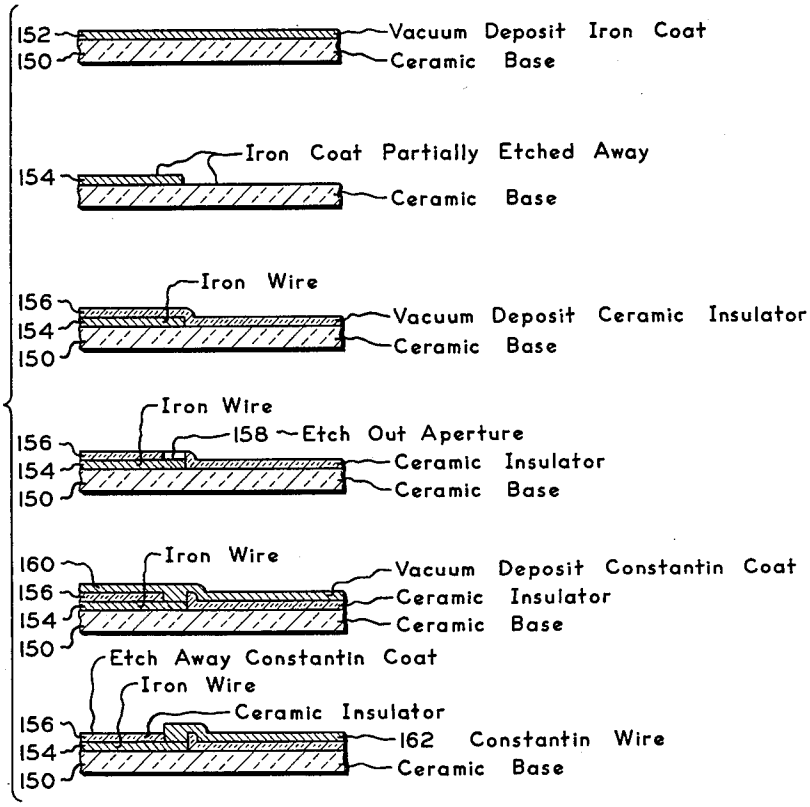
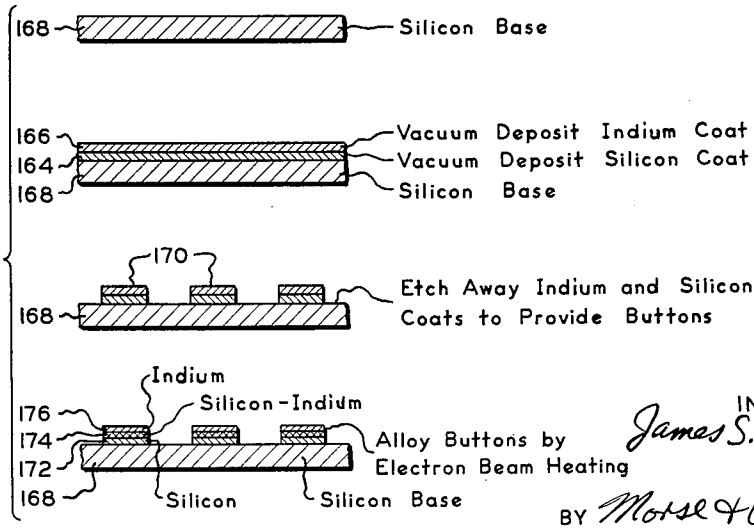


FIG. 4



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United States Patent Office 3,118,050 Patented Jan. 14, 1964

3,118,050

ELECTRON BEAM DEVICES AND PROCESSES

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6 Claims. (Cl. 219—117)

The present invention relates to devices and processes involving the application of an electron beam to a part being worked and, more particularly, to devices and processes in which a work-piece is treated, i.e. cut, etched, alloyed, etc. by one or more incident electron beams.

It is possible to vaporize, liquify or sinter portions of a work-piece in a substantial vacuum by an impinging electron beam. Such an electron beam, if applied intermittently in the form of high amplitude pulses, serves to heat incremental regions of the work-piece in such a way that a major proportion of the transmitted energy is absorbed rapidly by the increment toward which the electron beam is directed and a negligible proportion of the transmitted energy is transferred slowly to adjacent increments. Since the electron beam can be focused sharply and positioned precisely and since the work-piece is disposed in a substantial vacuum that is continuously exhausted, the geometrical and chemical conditions are such as to permit treatment of the work-piece on a microminiature scale. In such a system as the beam impinges upon the work-piece, the power generated by the beam and the information carried by the beam constitute distinct considerations.

The primary object of the present invention is to develop power in and impart information to the electron beam by using it as a medium for imaging an enlarged source configuration upon a microminiature work-piece to be treated. The enlarged configuration for example may be a slotted mask, through which a collimated beam of electrons is directed, or a photoemitting surface, from which electrons are emitted in response to an optical image. Since, once the source configuration and the work-piece are relatively positioned and the vacuum and electro-optical conditions are determined, the treatment proceeds without mechanical movement, microminiature results of unprecedented dependability are possible.

Other objects of the present invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the devices possessing the construction, combination of elements and arrangement of parts, and the processes possessing the various steps, their sequence and their interrelations, which are exemplified in the following detailed disclosure, and the scope of which will be indicated in the appended claims.

For a fuller understanding of the nature and objects of the present invention, reference should be had to the following detailed description, taken in connection with the accompanying drawings wherein:

FIG. 1 is a schematic view of an embodiment of the present invention, partly in fragmentary mechanical perspective and partly in electrical block diagram;

FIG. 2 is a schematic view of another embodiment of the present invention, partly in fragmentary mechanical perspective and partly in electrical block diagram;

FIG. 3 illustrates materials undergoing the steps of a process embodying the present invention; and

FIG. 4 illustrates materials undergoing the steps of another process embodying the present invention.

Generally, each of the devices described herein as embodying the present invention comprises a source configuration in the form of an apertured mask through which electrons are directed from a collimated electron beam or

a photo-emitting surface from which electrons are emitted by the action of incident light, a control system for pulsing the beam from the source configuration, a magnetic lens system for imaging the beam at a focal region, and holder at the focal region for positioning the work with respect to the beam, the source configuration being substantially larger than the focal region. Preferably the electron beam is modulated for a pulse amplitude ranging up to 150 kv., a pulse duration ranging from .01 microsecond to 1000 microseconds, a pulse repetition rate ranging up to 5000 per second and a pulse current ranging up to 500 milliamperes. Preferably the source configuration should be sufficiently larger than the focal region, i.e. at least 10 times as large, to minimize the current density at the source configuration for the purpose of limiting its heating and facilitating its adjustment. In other words, the larger the source configuration is with respect to the work-piece, the smaller is the undesired heating effect at the source configuration and the easier is its registration with the work-piece. The lens system, by analogy to photography, makes it possible to vary the intensity of the electron beam not only in a single step between cut-off and cut-on but also throughout an infinite range of steps therebetween. For example, the lens system may provide a field of varying intensity (analogous to shades of gray) if desired. During operation of the device, the hermetic enclosure is continuously evacuated by a mechanical fore-pump, a fluid diffusion pump and a gettering pump, which cooperate to maintain the pressure within the hermetic enclosure at an extremely low value, preferably less than 10^{-3} mm. Hg, notwithstanding any gaseous discharge from the work-piece.

FIG. 1 illustrates an apparatus embodying the present invention as comprising a hermetic housing **10** having a laterally extending box-like lower compartment **12** and a vertically upstanding sectional compartment for enclosing and supporting the operating components of the apparatus, which are now to be described. Laterally extending compartment **12** is provided with a closure **16** through which work-pieces **18** may be inserted into compartment **12** before the device is placed in operation. The work-pieces are carried by a holder **20**, which is guided for reciprocal movement by a pair of rails **22**, **24** and a threaded shaft **26**. One end of shaft **26** projects into a threaded bore **28** and its other end is rotated by a suitable motor **30**. A binocular microscope **32** is provided for observing the work-piece when properly positioned in compartment **12**. The work-piece may be treated by an electron beam that is generated by an electron gun **34**, collimated by a magnetic lens **36**, differentially attenuated by a mask **38**, and focused by a magnetic lens system **40**. Compartments **12** and **14**, in operation, are continuously evacuated by fore and diffusion pumps, shown generally at **17**.

Electron gun **34** includes a filament **42** for emitting electrons thermionically, a grid **44** for controlling the transmission of electrons therethrough, an anode **46** for accelerating electrons transmited through grid **44** and an insulating spacer **48**. Filament **42** is energized through an isolation transformer **50**, which is energized by a filament power source **52**. Grid **44** is maintained normally at a negative potential with respect to filament **42** by a suitable direct current source **54**, but is subjected to pulses of voltage from a pulse generator **56** in order to control high voltage applied to filament **42** by a high voltage source **57**. The number, amplitude, and frequency of pulses are determined by a suitable conrtol circuit **58**. Collimating lens **36** is in the form of a hollow annulus, the inner tubular surface of which is provided with a circumferential slot **60** and the interior of which contains a suitable coil **62**. Coil **62** is energized by an adjustable

direct current supply 64. The collimated beam of electrons from collimating lens 36 impinges upon mask 38 which is mounted on a suitable conducting support 66. Support 66 is adjustable in two horizontal dimensions by suitable micrometer screws 68. Support 66 is provided with a series of fiducial notches 70 through which rays of the electron beam may pass. As shown, focusing system 40 includes a pair of magnetic lenses 72, 74, each in the form of a hollow annulus, the inner tubular surface of which is provided with a circumferential slot 76. Both lenses are energized by independently adjustable direct current supplies 78. Holder 20 is provided with a series of fiducial notches 80. Within each of these notches is a terminal, insulated from the holder, to which a ray of electrons from its counterpart 70 in mount 66 is transmitted. By means of a suitable balanced pair circuit 82, mount 66 may be registered with mount 20 in extremely precise fashion. Balanced pair circuit 82 is a simple conventional comparator circuit of the type shown in FIG. 2 of U.S. Patent No. 3,038,078 issued in the name of Walter P. Kern on June 5, 1962.

In operation, first a series of work-pieces 18 are positioned within the open seats in holder 20. Next closure 16 is closed in order to hermetically seal the compartments of the device. Next, while these compartments are evacuated continuously, an electron beam from electron gun 34 is directed through collimating lens 36 and mask 38. The beam from mask 38 is focused by lens system 40 onto a work-piece 18 properly positioned in registration with mask 38. Proper registration of mask 38 and work-piece 18 is simply determined by adjusting micrometer screws 68 until balanced pair indicator 82 signifies proper registration. The work may be observed through binocular microscope 32 as processing progresses. By reason of the rail, screw and motor arrangement, a series of work-pieces 18 may be processed automatically without any necessity for opening the compartment.

FIG. 2 illustrates an alternative embodiment of the present invention as comprising a housing 90 having a laterally extending box-like compartment 92 and a vertically upstanding tubular compartment 94, both of which communicate with each other and are hermetically sealed, and a light-tight photographic compartment 96. Within light-tight compartment 96, in sequence, are a source of illumination 98, an optical collimating lens system 100, a series of photographic transparencies 102 and a focusing objective lens 104.

One of transparencies 102 is imaged by the foregoing optical system upon the lower face 106 of an optically flat disk 108, which hermetically seals chamber 94 from chamber 96. At lower face 106 is a semi-transparent cesium oxide coating that emits electrons in response to incident light. Electrons emitted by coating 106 are accelerated by grid 110 and focused by a magnetic lens system 112 onto a work-piece 114, which is mounted and positioned in the same manner as its counterpart in the device of FIG. 1. Grid 110 serves as an anode to accelerate the electrons emitted by coating 106 and is energized by a suitable direct current supply 116, which is fed through a transformer 118 by a suitable pulse to generator 120. The lenses of system 112, which are similar in every respect to their counterparts in the lens system of FIG. 1, are fed by suitable adjustable direct current supplies 122.

Within compartment 92 is a series of rings 124, 126 and 128, which are provided with beads 130, 132 and 134, respectively, of distinctive material to be evaporated. Each of beads 130, 132 and 134 is provided with a reflector that prevents evaporated material from escaping into undesired parts of the device. Rings 124, 126 and 128 are designed to be heated selectively by the passage of an electric current from power sources 136, 138 and 140 in such a way as to cause evaporation from the beads they carry toward the work-piece which is being processed. By a suitable sequence of evaporating and etching steps, a variety of microminiature structures may be produced. A system for automatically processing work-pieces in the foregoing way is shown as including a program control 142, which sequences the operation of a slide projector positioner 122, a pulse generator 120, a heater 136, a heater 138 and a heater 140.

FIG. 3 illustrates the steps of a process for fabricating a thermocouple in the device of FIG. 2 with an appropriate sequence of vacuum deposition steps effected by heating beads 130, 132 and 134 and etching and machining steps effected by electron bombardment under the control of a series of transparencies 102. First an iron coat 150 is deposited upon a ceramic base 152. Next iron coat 150 is partially etched away by electron bombardment to leave a wire 154. Next a ceramic coat 156 is deposited by evaporation. Next a hole 158 is machined by the electron bombardment through ceramic coat 156. Next a constantin coat 160 is deposited by evaporation. Finally constantin coat 160 is etched away to provide a wire 162. The product of this process is a microminiature iron-constantin thermocouple.

FIG. 4 illustrates the steps of a process for fabricating a transistor in the device of FIG. 2 with an appropriate sequence of vacuum deposition steps effected by heating beads and etching and machining steps effected by electron bombardment under the control of a series of transparencies 102. First a silicon coat 164 and an indium coat 166 are deposited by evaporation onto a silicon base 168. Then coats 164 and 166 are etched away to provide a series of buttons 170. Finally each button 170 is fused at its silicon-indium face to provide in sequence silicon, silicon-indium and indium strata 172, 174 and 176, which constitute a microminiature transistor.

This application is a continuation in part of co-pending patent application Serial No. 7049, filed February 5, 1960 in the name of James S. Hetherington for "Comprehensive Electron Beam Machining Devices."

Since certain changes may be made in the above devices and processes without departing from the scope of the invention herein involved, it is intended that all matter described in the foregoing description and shown in the accompanying drawing be interpreted in an illustrative and not in a limiting sense.

What is claimed:

1. Electron beam machining apparatus comprising means providing a vacuum compartment, a holder in said compartment at a first axial position for a work-piece, a source including means for emitting an electron flux in the axial direction toward said holder and means at a second position spaced from said holder for determining the original configuration of said electron flux transversely of said direction, a lens system for imaging said configuration with said electron flux to provide a reduced configuration at said first position, a control for moving said source and said holder relative to one another in two dimensions perpendicular to said axial direction in order to register said source and said holder, said original configuration being at least ten times as great in extent as said reduced configuration, and means for pulsating said electron flux at a pulse duration ranging from .01 to 1000 microseconds.

2. The electron beam machining apparatus of claim 1 wherein said means for determining said original configuration is a mask for said electron flux.

3. The electron beam machining apparatus of claim 1 wherein said means for emitting an electron flux comprises a photoemitting surface and said means for determining said original configuration in a mask adapted to differentially attenuate light that may be incident toward said photoemitting surface.

4. Micro-miniature etching apparatus comprising a hermetic enclosure and mounted therein, in sequence, a thermionic filament, a grid, a spacer, an anode, said grid and said anode being insulated from each other by said spacer, said grid and said anode being dished inwardly

toward each other and being centrally apertured, a collimating lens in the form of a hollow annulus and having a circumferential slot at its inner tubular surface and within the hollow region of said annulus a coil, a first support for a mask, said first support providing a plurality of alignment openings and means for adjusting the position of said first support within said enclosure, a plurality of focusing lenses, each focusing lens of said plurality being in the form of a hollow annulus and having a circumferential slot at its inner tubular surface and within the hollow regions of said annulus a coil, a second support for a workpiece, said second support having a plurality of detecting elements, said mask being at least ten times greater in extent than said workpiece, said detecting elements and said alignment openings being similarly positioned, the collimating and focusing lenses serving to image said mask on said workpiece with an electron flux emitted by said thermionic filament, said collimating and focusing lenses serving to image said alignment openings on said detecting elements, means for evacuating said enclosure, means for applying power to said filament, means for establishing an intermittent high potential between said anode and said grid in order to impart sequential pulsations to said flux, and means for indicating the correctness of the alignment of said mask and said workpiece in response to signals generated by said detecting elements, said sequential pulsations being characterized by a pulse duration ranging from .01 to 1000 microseconds.

5. Micro-miniature etching apparatus comprising an enclosure and mounted therein in a sequence, a source of electromagnetic radiation, collimating means for said electromagnetic radiation, a photographic transparency, a

focusing lens for imaging said transparency at a focal surface with said electromagnetic radiation, a photoemitting element for generating an electron flux corresponding to electromagnetic radiation incident upon said photoemitting element, lens means for imaging said electron flux at a focal surface and holding means for positioning a workpiece at said last mentioned focal surface, and means for moving said transparency and said holding means in two dimensions relative to each other perpendicular to the direction of said sequence in order to register said transparency and said holding means.

6. The micro-miniature etching apparatus of claim 5 comprising a plurality of alignment elements at said transparency and a plurality of detecting elements at said workpiece, said alignment elements and said detecting elements being similarly positioned, and indicating means responsive to signals from said detecting elements in order to indicate the correctness of the registration of said transparency and said workpiece.

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