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[72] Inventor Graham Stuart Plows, 80 Brent Court, Hertfordshire, and William Charles Nixon, 2 Causewayside, San Causeway, Cambridge, both of England

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[54] SCANNING ELECTRON MICROSCOPE FOR EXAMINING A REPETITIVELY VARYING PHENOMENON AT THE SURFACE OF A SPECIMEN
3 Claims, 4 Drawing Figs.

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[51] Int. Cl. H01j 37/28, H01j 37/22
[50] Field of Search .... 250/49.5 A, 49.5 R, 49.5 PE, 49.5 E; 178/6.8 DIG 1

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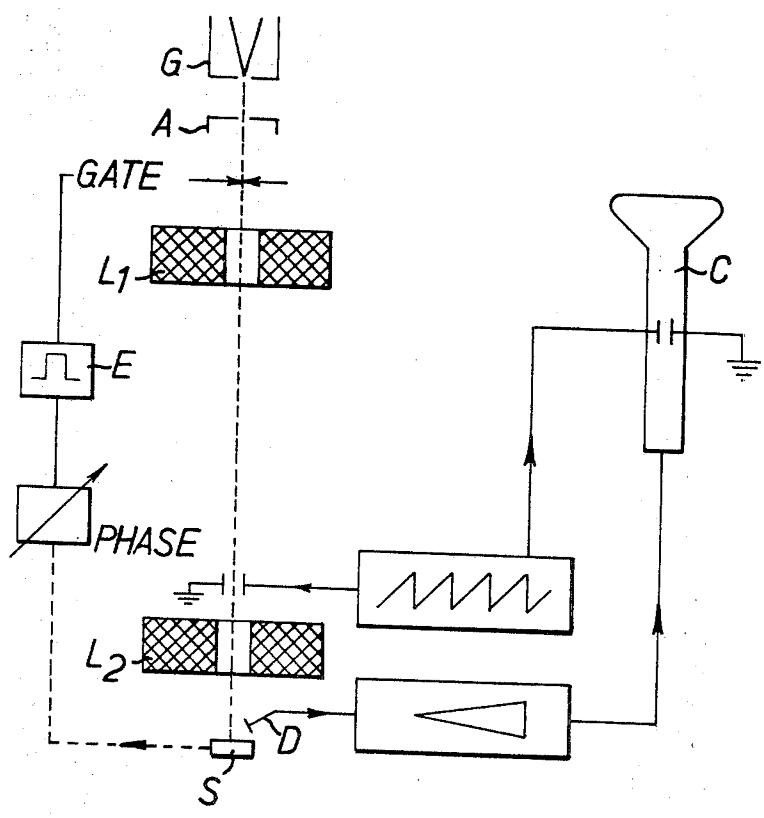
Primary Examiner—Anthony L. Birch
Attorneys—Scrivener, Parker, Scrivener and Clarke

ABSTRACT: In time-sequential scabbibg electron microscopy in which an image is reconstructed for example on the screen of a cathode ray tube, rapidly varying phenomena having a cycle period much shorter are examined stroboscopically by gating the signal train, preferably the incident electron beam, in synchronism with the phenomenon and the image is built up from the resulting train of successive signals.



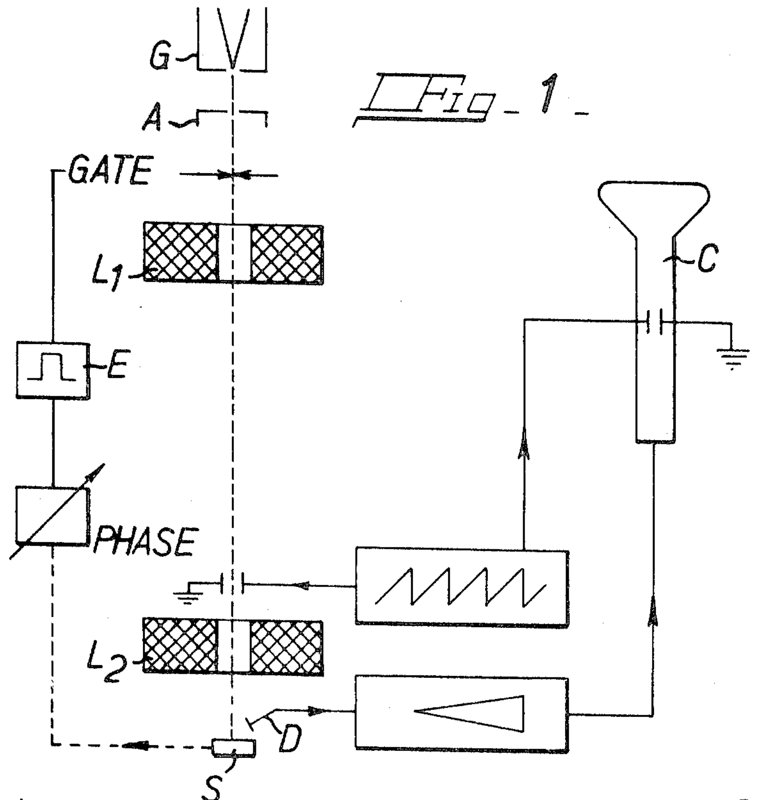


Fig. 1

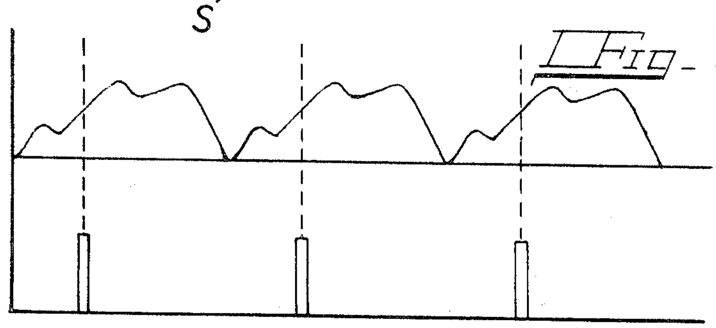


Fig. 2

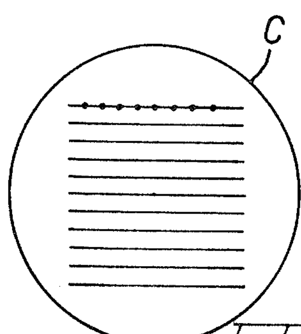


Fig. 3

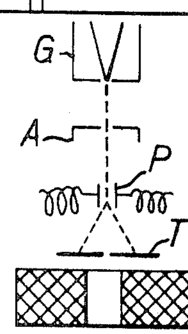


Fig. 4

SCANNING ELECTRON MICROSCOPE FOR EXAMINING A REPETITIVELY VARYING PHENOMENON AT THE SURFACE OF A SPECIMEN

This invention relates to electron beam apparatus, in which a beam of electrons, generally focussed down to very fine transverse dimensions, is caused to impinge on a specimen to be examined or analysed. The invention is applicable primarily to scanning electron microscopes but, as will become apparent later, it may be applied to other electron beam apparatus such as electron probe microanalysers.

In conventional electron microscopes involving flood electron illumination of a thin specimen and the direct formation of an image of the illuminated area of the specimen by means of an electron lens system, it has been proposed to employ stroboscopic principles, exactly analogous to those used in optical apparatus for examining rapidly recurring and repetitively varying phenomena. Here, as in the optical analogy, the illumination is pulsed so that it is switched on only for a brief moment at corresponding instants in each cycle of the recurring phenomenon. The analogy with the optical equivalent is straight forward, in that a complete image of the illuminated body is formed at each such instant, the object and image planes being conjugate.

The basis of the present invention lies in the appreciation that it is possible to apply stroboscopic principles to scanning electron probe apparatus, despite the fact that no instantaneous complete image is formed. According to the invention we propose to provide electron beam apparatus for examining rapidly recurring and repetitively varying phenomena in specimens by scanning the specimen in a line or a raster with an electron probe at a line frequency or frame frequency which is only a fraction of the repetition frequency, feeding the resulting time varying signal picked up from the specimen to a recorder, for example a cathode ray tube, which is scanned in synchronism with the scanning of the beam, and pulsing or gating the beam or the signal in synchronism with the recurring phenomenon so that the beam or the signal is only passed for a brief period during each cycle or group of cycles of the phenomenon.

The resultant image on the face of the cathode ray tube or other recorder is thus a series of dots, each showing the state of that point on the specimen on which the beam is impinging at the instant in question, and each of these instants being at the corresponding point in the cycle of the varying phenomenon. Thus the dots, taken together, build up, in a total time lasting many complete cycles, an overall picture of the state of the specimen at a single instant in the cycle.

Provided the scanning frequency is at least one or two orders lower than the repetition frequency of the phenomenon being examined, the dots can be so close that they overlap and so no spatial information is lost, and provided the scanning frequency is greater than about twenty frames a second, or a screen with an adequate after-glow is used, an apparently complete image is obtained, and can be observed directly like a normal stroboscopic image. Where photographic observation of the c.r.t. screen or other recorder is used the scanning frequency can be as low as desired.

By the use of the invention we obtain the known advantages of scanning microscopy over transmission microscopy, the most important one being the fact that one can examine opaque surfaces. At the same time we obtain the important advantage of stroboscopic techniques, namely, of being able to "freeze" a cyclically varying or repeated phenomenon at any selected instant in the cycle, and thus examine statically the behaviour under dynamic conditions.

The invention will now be further described by way of example with reference to the accompanying drawings, in which:

FIG. 1 illustrates diagrammatically a standard scanning electron microscope to which the invention has been applied;

FIG. 2 is a pair of graphs illustrating the application of the stroboscopic technique;

FIG. 3 is a diagrammatic representation of the screen of the cathode ray tube on which an image is built up; and

FIG. 4 shows a preferred method of gating to obtain the stroboscopic effect.

Referring first to FIG. 1, a scanning electron microscope comprises an electron gun G with an anode A through which an electron beam passes to be focussed by first and second electron lenses L_1 and L_2 onto a specimen S under examination. The beam can be focussed down to a diameter of the order of only a micron, and it is caused to scan over a selected region of the specimen in the manner of a television raster, covering an area which measures, for example, a few tens or hundreds of microns each way. The secondary electrons emitted by the specimen are picked up by a detector D to produce an electrical contrast signal that is amplified and used to control the brightness of the trace of a cathode ray tube C, the beam of which is caused to scan the screen in synchronism with the electron beam that impinges on the specimen. In this way an image of the scanned area of the specimen is built up in a time sequence, and any constant or only slowly changing phenomenon in the specimen, such as voltage contrast between different regions of the area scanned, or electric or magnetic field that produces a change in the number of secondary electrons picked up by the detector as the beam scans the surface of the specimen, will produce a contrast signal that results in a two-dimensional image on the cathode ray tube screen showing the spatial distribution of that phenomenon. The frame frequency, i.e. the repetition rate of the total scanning cycle, will depend on the sensitivity required, and it may take several seconds, or even longer, to build up one complete image where the contrast is low, and then a screen with a long delay time, or a storage tube is used, or the image is recorded photographically.

However, where the phenomenon under examination is not constant but is varying cyclically at a rate comparable with or higher than the frame frequency, the time sequential image builtup on the screen of the cathode ray tube will be meaningless, as the individual elements of the overall picture will represent the condition of the corresponding elements of the specimen at different times.

We solve this by switching the signal on only at corresponding instants in each cycle, in a manner analogous to that of ordinary stroboscopic techniques. We can do this switching at any point in the chain between the point of generation G of the electron beam and the control electrode of the cathode ray tube, i.e. we could interrupt the incident beam or picked-up signal and the stroboscopic effect would by the same. However, as the detail in the ultimate display is dependent on the bandwidth of the weakest link in the chain up to the point of switching it is logical to switch as early as possible in the chain, which in practice means gating the electron beam immediately after it has been formed, as indicated by the arrow in FIG. 1. The electron beam is allowed through by this gate only for a brief fraction of each cycle of the varying phenomenon in the specimen. This could be done by a generator E synchronised with the varying phenomenon and producing short pulses as indicated by the lower graph in FIG. 2, the upper graph showing a typical repetitively varying phenomenon. These pulses may be used to gate the beam in one of various ways; for example the usual Wehnelt cylinder or another suitably placed grid could be biassed negatively to cut off the beam, and the pulses are fed to this electrode in a positive-going sense to switch the beam on at the required instant. The pulse frequency will normally be equal to that of the varying phenomenon but could of course be a sub-multiple.

Between successive pulses of electrons reaching the specimen and producing a signal in the detector D, the beam will have moved across the specimen a small distance, and so the signals will appear as a train of dots on the screen of the cathode ray tube C, as indicated in FIG. 3. However, as long as the frequency of the recurring phenomenon is sufficiently high these dots will overlap and in practice a complete image will be build up, over a full scanning cycle, showing the state of the scanned area of the specimen at a selected instant in the cycle of the recurring phenomenon. The detail and spatial resolution are equal to those in a normal continuous-beam scanning electron microscope.

The phase of the gating pulse in relation to the varying phenomenon is made variable, as indicated in FIG. 1, to enable the user to observe the image at any desired instant in the cycle.

The resolution in time, i.e. the ability to detect changes between closely adjacent points in the cycle, depends on the sharpness and duration of the pulse. It is difficult to obtain from a pulse generator the idealised narrow square-edged pulse of the lower graph of FIG. 2 at high repetition rates of the order of megahertz, and in practice we prefer to switch the beam on and off by the means shown in FIG. 4. Between the electron gun G and the first lens L_1 we insert a slit T and by the use of deflection plates P, to which a simple sinusoidal deflecting voltage is applied, we cause the beam to be deflected sinusoidally, as indicated by the broken lines, so that it only passes through the slit for a brief instant twice in each cycle. The resulting pulse has sharp leading and trailing edges and, if the deflection amplitude is made sufficiently large in relation to the width of the slit, the pulse can be of very short duration. In fact the pulse duration can be varied by altering the amplitude, and this may be an advantage where it is necessary to strike a balance between resolution (in time) and signal strength.

It will be understood that the frequency of the deflecting voltage applied to the plates P will normally be half the frequency of the recurring phenomenon.

In a typical example a phenomenon varying at a frequency of 7 MHz was examined at a frame scanning frequency of one Hertz with a gated pulse length of 10 nanoseconds so that the image on the screen of the cathode ray tube was made up of seven million dots, which merged to produce a spatially continuous image of the state of the specimen at a selected instant in the cycle of the varying phenomenon.

The invention is of particular value in the examination of the dynamic voltage distribution in electric circuit elements, for example in semi-conductor devices and especially in microminiature integrated circuit elements and high speed switching circuits. This can reveal dynamic behaviour and voltage patterns not predictable and not revealed by examining the pattern obtained under static conditions. The dynamic behaviour of electro-mechanical filters under working conditions can also be examined. Where the phenomenon to be examined is a voltage distribution a particularly suitable form for the detector D is that disclosed in our British Patent Application No. 300/69.

It will be understood that the invention can be used to investigate and "freeze" any cyclically varying or repetitively occurrring phenomena that can produce a detectable contrast signal capable of being fed to a recorder. For example mechanical vibrations on a microscopic scale and magnetic field distributions under dynamic conditions can be examined, and also biological specimens, both their mechanical oscillations and electrical or bio-magnetic behaviour. The detector D need not be an electron detector, but could detect any radiation which is capable of producing a contrast signal in response to the impact of the electron beam.

If a continuous plot is required of the variation of the cyclic phenomenon with time, the beam can be stopped at any selected point of the scanned area and then the means which control the phase of the gating pulse or deflection signal with respect to the cycle can be traversed through the whole of the range to display the waveform on the recorder, as in the sampling oscilloscope.

We claim:

1. A method of examining a rapidly repetitively varying phenomenon at the surface of a specimen by the use of electron beam apparatus, said method comprising the steps of generating a finely focussed electron beam, forming said beam into a train of pulses by interrupting said beam at a frequency which is equal to or a low submultiple of the frequency of the repetitive variations of said phenomenon, causing said beam to impinge on said surface only as a train of pulses in synchronism with said phenomenon the pulses striking said surface only at one instant in the cycle of the repetitive variations of said phenomenon, displacing said beam laterally such as to cause said beam to scan said surface in a time-sequential manner at a repetition frequency which is of a lower order than the repetition frequency of said phenomenon whereby said pulses strike said surface at successive points at said selected instant, generating electrical signals in response to the impact of said pulses on said surface, the magnitude of said signals being dependent on the effect of said phenomenon at said selected instant of impact of said pulses and applying said signals to a recorder while causing said signals to scan said recorder in a time-sequential manner in synchronism with the scanning of said surface by said beam, whereby to construct in said recorder, in the form of a succession of individual points corresponding to said pulses, an image of said surface having a pattern dependent on the value of said phenomenon at said selected instant in the cycle of its repetitive variations.

2. A method of examining a rapidly repetitively varying phenomenon at the surface of a specimen by the use of electron beam apparatus comprising the steps of generating a finely focussed electron beam, causing said beam to impinge on said surface, displacing said beam laterally such as to cause said beam to scan said surface in a time-sequential manner at a repetition frequency which is of lower order than the repetition frequency of said phenomenon, generating an electrical signal in response to the impact of said beam on said surface, the magnitude of said signal being dependent on the effect of said phenomenon from instant to instant, interrupting said signal at a frequency which is equal to or a low submultiple of the repetition frequency of said phenomenon to convert said signal into a train of pulses in which the magnitude of successive pulses are dependent on the effect of said phenomenon at successive points in said scan at one instant in the cycle of repetitive variations of said phenomenon, shifting the phase of interruption of said signal in relation to the phase of said varying phenomenon to select said one instant in the cycle of repetitive variations of said phenomenon, and applying said pulses to a recorder while causing said pulses to scan said recorder in a time-sequential manner in synchronism with the scanning of said surface by said beam, whereby to construct in said recorder, in the form of a succession of individual points corresponding to said pulses, an image of said surface having a pattern dependent on the value of said phenomenon at said selected instant in the cycle of its repetitive variation.

3. Apparatus for producing a time-sequentially constructed image of a surface of a specimen representative of its state at a predetermined instant in the cycle of a rapidly repetitively varying phenomenon at said surface, comprising means for generating a finely focussed electron beam, means causing said beam to impinge on said surface, scanning means operable to cause said beam to scan said surface repetitively in a time-sequential manner, detector means generating an electric signal in response to the impingement of said beam on said surface such that the magnitude of said signal is dependent on the value of said phenomenon at the point of impingement on said surface, recording means, and means feeding said signal to said recording means and causing said signal to scan said recording means in a time-sequential manner in synchronism with said first-mentioned scanning means, interrupter means operable to interrupt the information path between

said beam-generating means and said recording means in synchronism with the repetition of said phenomenon and to cause said recording means to receive said signal as a train of pulses, each pulse arriving at the recorder at one instant in the cycle of the repetitive variations of said phenomenon, and variable phase shifting means operable to shift the phase of operation of said interrupter means in relation to the phase of repetition of said varying phenomenon to select said predetermined instant in the cycle of repetition of said varying phenomenon.

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