

Dec. 13, 1966

C. W. HAAS ETAL

3,292,058

THIN FILM CONTROLLED EMISSION AMPLIFIER

Filed June 4, 1963

Fig. 1.

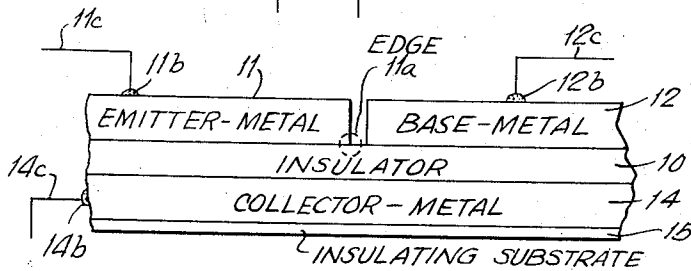


Fig. 2.

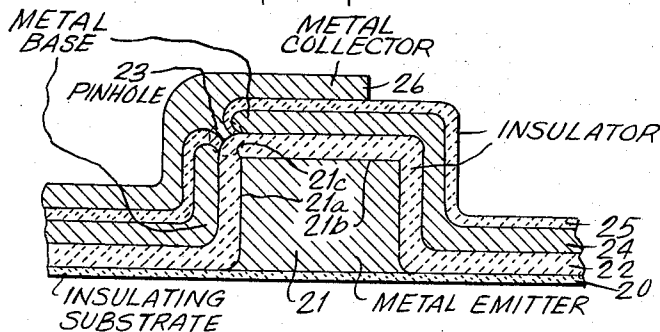
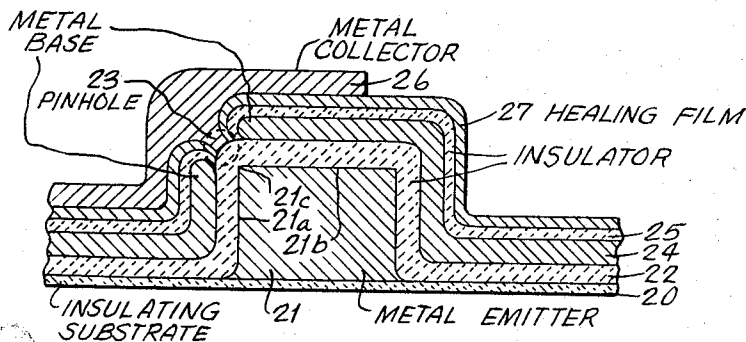


Fig. 3.



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THIN FILM CONTROLLED EMISSION AMPLIFIER
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Filed June 4, 1963, Ser. No. 285,266

7 Claims. (Cl. 317-235)

This invention relates to thin film structures. More particularly, this invention relates to thin film controlled emission amplifiers. Still more particularly, this invention relates to evaporated thin film devices useful as amplifiers.

Devices or structures are known for controlling the emission of electrons from a conductor into an insulator. One such device for controlling electron emission into an insulator is known as a depletion layer transistor which in its thin film version is usually referred to as a metal-interface amplifier. A metal-interface amplifier, however, requires a single crystal semi-conductor for the collector. The fabrication of a single crystal semi-conductor useful in metal-interface amplifiers is difficult and requires highly specialized techniques. Also, a device which requires a single crystal film or a single crystal substrate, as in the instance of a metal-interface amplifier, is undesirable from a production or fabrication point of view. Further, a requirement that a device employ or embody a single crystal or a single crystal substrate reduces the compatibility of the device with thin film integrated circuits.

It is an object of this invention to provide a device for controlling the emission of electrons from a conductor into an insulator.

Another object of this invention is to provide a thin film controlled emission amplifier.

Still another object of this invention is to provide a thin film controlled emission amplifier which can be produced by evaporation or vaporization and condensation of the component materials making up the device.

How these and other objects of this invention are accomplished will become apparent in the light of the accompanying disclosure made with reference to the accompanying drawings wherein:

FIG. 1 schematically shows in cross section a thin film device having a planar configuration in accordance with one embodiment of this invention;

FIG. 2 schematically shows another embodiment of a thin film controlled emission amplifier fabricated in accordance with this invention; and wherein

FIG. 3 schematically shows still another embodiment of a thin film controlled emission amplifier fabricated in accordance with this invention.

The thin film devices of this invention are based on electron emission from the edge of a conductor into an insulator, the so-called "edge effect." In devices fabricated in accordance with this invention the electron emission from the edge of a conductor into an insulator is controlled by a closely adjacent metallic film. The control of electron emission by the closely adjacent metallic film is in a manner analogous to the electron emission control effected in a depletion layer transistor, more specifically a thin film version of the depletion layer transistor usually referred to as metal-interface amplifier.

The advantage of the thin film device of this invention over a metal-interface amplifier resides in the fact that the thin film devices of this invention do not require a single crystal semi-conductor for the collector. In the devices of this invention a metal collector film and a thin film insulator replace the single crystal semi-conductor and its depletion region of a metal-interface amplifier. This feature of the invention makes the fabrication of

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these devices compatible with the production of passive thin film elements.

Referring now to FIG. 1 of the drawings which illustrates in cross section a thin film controlled emission amplifier or so-called edge effect triode of this invention, the illustrated device having a substantially planar configuration, the emitter-collector current through insulator film 10, such as a thin film of aluminum oxide, is particularly large at an edge, dashed-line circled region 11a, of emitter 11. It is suggested that (as in the case of the metal-interface amplifier) the electron emission from edge 11a of metal emitter 11 through insulator 10 to metal collector 14 is controlled by the potential of metal base 12 which is near the edge of metal emitter 11 as illustrated. In the device illustrated there is very little feedback. Insulator 10, which replaces the single crystal semi-conductor depletion region of a metal-interface amplifier, improves the performance of the device since it can present a higher output impedance.

In the fabrication of a device illustrated in FIG. 1 an electrically conductive metal, such as aluminum, is deposited, such as by vapor deposition, onto inert insulating substrate 15, such as glass or other temperature resistant material, e.g. a ceramic material, to form metal collector film 14. Insulator film 10, such as a film of aluminum oxide, Al_2O_3 , is evaporatively deposited upon collector film 14 directly by vaporization of metallic aluminum in the presence of an oxygen-containing atmosphere.

Insulator film 10 may be formed by oxidizing the surface of aluminum collector film 14 by exposing film 14 to an oxygen-containing atmosphere or by anodization (wet, dry or gaseous). The thickness of the aluminum oxide insulating film so formed can be accurately controlled by controlling the temperature and length of time of exposure of the metallic aluminum film to the oxygen-containing atmosphere or by the anodization voltage. There is then deposited upon one portion of insulator film 10 a film of electrically conductive metal 11 to serve as the emitter. Metal emitter film 11 is also desirably evaporatively deposited.

In the fabrication of the device metal emitter film 11 is deposited on insulator film 10 so as to form edge 11a defined by the junction of a surface of metal emitter film 11 with the surface of the insulator film 10, such as illustrated in FIG. 1.

In substantially the same manner a film of electrically conductive metal 12 to serve as the metal base is also deposited on insulator 10, as illustrated in FIG. 1. Metal emitter film 11 at edge 11a, however, is spaced closely adjacent but out of direct contact from metal base film 12 in closely adjacent but separated edge-to-edge-relationship. Desirably, insulating material, preferably the same as insulating material making up insulator film 10, separates the adjacent edges of metal films 11 and 12. Ohmic connections 11b, 12b, and 14b attached to metal emitter film 11, metal base film 12 and metal collector film 14 are provided with conductors 11c, 12c and 14c, respectively, for the application of the necessary voltages for effecting electron emission from region 11a of emitter 11 to collector film 14 and the control of such electron emission by metal base film 12.

Referring now to FIG. 2 of the drawings which schematically shows a special embodiment of a thin film controlled emission amplifier in accordance with this invention, there is illustrated deposited on suitable insulating substrate 20, such as glass, metal body 21 identified as metal emitter. The configuration of metal body or metal emitter 21 is such that an edge is formed on metal emitter 21 by the junction of two surfaces thereof, such as the junction of surfaces 21a and 21b, to form edge 21c.

The metal making up metal emitter 21 may be any suitable electrically conductive metal, such as gold, aluminum, tantalum, nickel and the like, preferably a metal which can be readily evaporatively deposited on a substrate.

Covering metal emitter 21 is electrically insulating film 22, desirably also evaporatively deposited. Insulating film 22 may be made of any suitable electrically insulating material which can be evaporatively deposited or otherwise formed or deposited on metal emitter 21. Aluminum oxide is a suitable material for insulating film 22. Following the deposition of insulating film 22, layer or film 24 of electrically conductive metal to serve as the metal base is evaporatively deposited or otherwise formed onto film 22. Metal base film 24 is deposited so as to substantially completely cover insulating film 22 but is deposited so that one or more pinholes 23 are provided in metal base film 24 closely adjacent or substantially along edge 21c of metal emitter 21. Aluminum is a suitable material for making up metal base film 24.

A relatively thin insulating film 25 is then deposited or otherwise suitably formed on metal base film 24 but not completely filling the pinholes therein. Aluminum oxide is a suitable material for insulator film 25. Electrically conductive metal collector film 26 is then evaporatively deposited or otherwise formed onto insulator film 25 so that metal collector film 26 extends into and is deposited within pinholes 23 provided in metal base film 24 to substantially completely fill the same. The metal making up that portion of film 26 within pinhole 23 comes into contact with insulator film 25 and is surrounded or enclosed by metal base film 24. Within pinhole 23 insulating film 25 serves as an insulating layer between that portion of metal collector film 26 within pinhole 23 and metal base film 24. Desirably, in an operational device suitable ohmic connections, not shown, are provided on metal emitter 21, metal base film 24 and metal collector film 26 for the application of operational and controlling voltages thereto by suitable means, not shown, for the control of current flow in the illustrated device.

Reference is now made to FIG. 3 of the drawings which illustrates another embodiment of a thin film controlled emission amplifier in accordance with this invention and wherein the same components are identified by the same reference numerals as employed in connection with FIG. 2. FIG. 3 illustrates a thin film controlled emission amplifier wherein insulating film 25 is provided with self-healing properties. Specifically, self-healing properties are imparted to insulating film 25 by depositing thereon or providing in contact therewith, suitably intermediate metal collector film 26 and insulating film 25, healing film 27, which may be conductive or non-conductive, preferably non-conductive or insulating. Healing film 27 is made up of compound M_2X wherein M_2 is a metal having a lower electrode potential or oxidation-reduction potential or a position in the electromotive or electrochemical series of the elements lower than metal M_A , metal base film 24 being made up of metal M_A , and wherein X is selected from the group consisting of non-metallic elements and radicals reactive with said metal M_2 to form said compound M_2X , the chemical relationship between M_2X and M_A being such that M_A reacts with M_2X to yield compound M_AX , M_AX being electrically insulating. Desirably, compound M_AX makes up insulating film 25. In compound M_AX the X component is as above defined and may be the same as or different from the X component of M_2X . Also, the metal making up collector film 26 is the same as metal M_2 or occupies a position in the electromotive or electrochemical series of the elements lower than metal M_2 .

The preparation and composition of the self-healing insulating films and the deposition or forming of thin films, such as thin films of electrically conductive metal or electrically insulating material, such as aluminum oxide, are described in copending, coassigned patent application

Serial No. 248,112, filed December 28, 1962 in the name of S. R. Pollack and C. E. Morris, S. R. Pollack being one of the coinventors herein. The disclosures and teachings of the above-identified patent application are herein incorporated and made part of this disclosure.

The function of healing film 27 is to preserve the integrity of insulating film 25. By way of explanation of the action and function of healing film 27, assume a device of the type illustrated in FIG. 3 is made employing gold or other suitable noble metal for metal collector film 26, lead oxide for healing film 27, aluminum oxide for insulating film 25 and metallic aluminum for metal base film 24. Further assume for some reason, due to overload, insulating film 25 fails or is punctured, thereby exposing lead oxide healing film 27 to direct contact with aluminum metal base film 24. The lead oxide of healing film 27 upon contact with the aluminum of metal base film 24 chemically reacts to form metallic lead and aluminum oxide. The thin-formed aluminum oxide "heals" the puncture in insulating film 25 thereby restoring the integrity of film 25.

Various materials may be employed in the practice of this invention for the formation of the metal emitter, metal base and metal collector components of the subject thin film devices and for the formation of the insulating films separating these components. Suitable materials for forming the metal collector films and/or the metal base film include aluminum, tantalum, chromium, gold, nickel and the like. The metal emitter film may be made of any of the so-called valve metals, such as tantalum, niobium, aluminum, zirconium, hafnium, tungsten, bismuth, antimony, beryllium, magnesium, silicon, germanium, tin and titanium. The insulating films 10, 22 and 25 may be the insulating oxides of the above metals or insulating compounds, such as the halides of these metals, e.g. MgF_2 , CaF_2 and the other alkaline earth metal halides. Particularly suitable for the electrically insulating films is aluminum oxide. A layer of lead oxide has been found to be useful in association with a thin film of aluminum oxide deposited upon a suitable metal substrate, such as aluminum, to impart self-healing properties to the aluminum oxide film. Desirably, in the fabrication of the subject thin film devices a noble metal, such as gold, silver, platinum, palladium and the like, is employed to form the metal collector film.

In the fabrication of the special devices or thin film structures of this invention various film thicknesses are employed. Usually the thickness of the metal emitter is in the range from about 1000 Å. and higher; the thickness of this film is not critical. The metal base film usually also has a thickness in the range from about 1000 Å. and higher; the thickness of this film is also not critical. The insulating films such as insulating films 10 and 22 of the drawings, usually have a thickness in the range from about 100 to about 500 Å., more or less. Insulating film 25 of the drawings, however, should have a thickness less than that of insulating films 10 and 22, such as a thickness from about 100-200 Å., more or less, to as small as about 10-25 Å.

As will be apparent to those skilled in the art in the light of the foregoing disclosure, many modifications, alterations and substitutions are possible in the practice of this invention without departing from the spirit or scope thereof.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A thin film structure comprising an electrically conductive metal emitter deposited upon an insulating substrate, said metal emitter being deposited on said insulating substrate in a conformation such that said metal emitter presents an edge formed by the junction of two surfaces of said metal emitter, a first insulator film deposited on said metal emitter, a film of an electrically conductive metal base deposited on said first film of insu-

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lator, said film of metal base having a pinhole opening therethrough located at that portion thereof on said first insulator film lying along the edge of said metal emitter, a second insulator film covering said metal base but not filling said pinhole in said metal base and an electrically conductive metal collector film deposited on said second insulator film extending through said pinhole to contact said first insulator film.

2. A thin film structure in accordance with claim 1 wherein the material making up said first insulator film and said second insulator film is aluminum oxide, Al_2O_3 .

3. A thin film structure in accordance with claim 1 wherein the material making up said metal emitter, said film of metal base and said metal collector film is metallic aluminum.

4. A thin film structure in accordance with claim 1 wherein the material making up said first insulator film and said second insulator film is aluminum oxide, Al_2O_3 , and wherein the material making up said metal emitter, said film of metal base and said metal collector film is metallic aluminum.

5. A thin film structure comprising an electrically conductive metal emitter deposited upon an insulating substrate, said metal emitter being deposited on said insulating substrate in a conformation such that said metal emitter presents an edge formed by the junction of two surfaces of said metal emitter, a first insulator film deposited on said metal emitter, a film of an electrically conductive metal base deposited on said first film of insulator, said film of metal base having a pinhole opening therethrough located at that portion thereof on said first insulator film lying along the edge of said emitter, a second insulator film covering said metal base but not filling said pinhole in said metal base, an electrically conductive metal collector film superimposed on said second insulator film extending through said pinhole to contact said first insulator film, the aforesaid second insulator film being a self-healing insulator film wherein a third film is deposited on said second insulator film between said second insulator film and said metal collector film, said film of metal base comprising metal M_A , said third film comprising compound M_2X wherein M_2 is a metal having a position in the electromotive or electrochemical series of the elements lower than M_A and X is selected from the group consisting of non-metallic elements and radicals reactive with metal M_2 to form said compound

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M_2X , the chemical relationship between M_2X and M_A being such that M_A reacts with M_2X to yield compound M_AX , M_AX being electrically insulating, said second insulator film comprising the compound M_1X wherein M_1 is a metal and X is selected from the group consisting of non-metallic elements and radicals reactive with metal M_1 to form compound M_1X and wherein said metal M_1 has a position in the electromotive or electrochemical series of the elements higher than metal M_2 and wherein the chemical relationship between M_2X and M_1 is such that M_1 reacts with M_2X to yield compound M_1X , M_1X being electrically insulating.

6. A thin film structure in accordance with claim 5 wherein metals M_1 and M_A are the same.

7. A thin film structure in accordance with claim 5 wherein metals M_1 and M_A are aluminum.

References Cited by the Examiner

UNITED STATES PATENTS

1,877,140	9/1932	Lilienfeld	317—230
2,552,052	5/1951	Matare	317—236
2,648,805	8/1953	Spenke et al.	317—235
2,680,220	6/1954	Starr et al.	317—235
2,894,184	7/1959	Veach et al.	317—236
2,918,628	12/1959	Stuetzer	317—235
3,056,073	7/1962	Mead	317—234
3,066,247	11/1962	Robinson	317—230
3,093,754	6/1963	Mann	317—234
3,116,427	12/1963	Giaever	317—235
3,184,659	5/1965	Cohen	317—234
3,204,161	8/1965	Witt	307—88.5

FOREIGN PATENTS

1,287,954	2/1962	France.
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OTHER REFERENCES

O'Brien et al.: IBM Technical Disclosure Bulletin, "Grid Controlled Tunnel Emission Amplifier"; November 1961, vol. 4, No. 6, page 22.

Mead: Journal of Applied Physics, "Operation of Tunnel Emission Devices," by Mead, April 1961, vol. 32, No. 4, pages 646—652.

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