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2,835,810

CRYSTAL RECTIFIER

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FIG. 1A

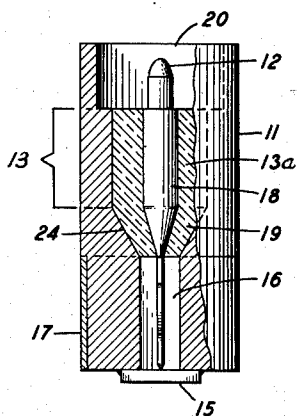


FIG. 1B

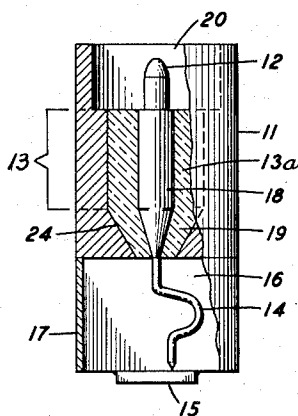


FIG. 1C

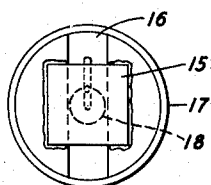


FIG. 2

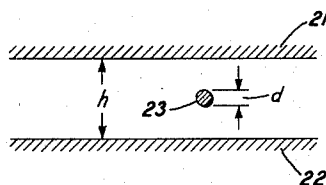


FIG. 3

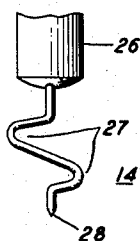
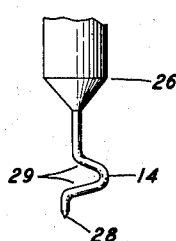


FIG. 4



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CRYSTAL RECTIFIER

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7 Claims. (Cl. 250—31)

This invention relates to crystal contact devices and more particularly to devices especially suited for use at wavelength bands below ten centimeters.

Crystal contact devices comprising a fine wire, often referred to as the cat whisker or spring wire, in point contact with a crystal of semiconductive material, such as selenium, silicon, germanium, or the like, and generally called crystal rectifiers, have been used at relatively short wavelengths. These devices include an outer conductive shield or tube into which are fitted an insulator supporting the spring on a stud and a conductive body supporting the crystal. Thus, the crystal device is built into a short section of coaxial line. A device of this general type is shown, for example, in Fig. 3 of U. S. Patent No. 2,415,841, issued February 18, 1947, to R. S. Ohl. Such a device may be used to terminate a coaxial transmission line or, with the aid of suitable transformers, a wave guide transmission line, particularly in microwave mixers and converters.

The cat whisker has long been a significant component of the crystal rectifier. In microwave crystal rectifiers the cat whisker has been generally fabricated from tungsten wire in the form of an S or modified C. In either of these forms, inductance associated with the spring has been a source of reflections of microwave energy and of bandwidth limiting when the rectifier is employed in a mixer. Although this limitation of crystal rectifiers has not in the past prevented their use in the microwave range, it has become increasingly important with the introduction in recent years of new and broader band devices, such as the traveling wave tube described, for example, in U. S. Patent No. 2,636,948, issued to J. R. Pierce on April 28, 1953. These new devices leave the crystal rectifier with its spring as a major bandwidth limiting element in microwave equipment.

Accordingly, it is an object of the present invention to improve the electrical characteristics of crystal rectifiers. Another object is to increase the bandwidth of such devices. A still further object is to minimize reflections of the microwave signal applied to such devices.

A feature of the present invention is the accomplishment of the above objects without sacrificing the advantages of the coaxial structures of the prior art.

Other objects and features of the present invention will become apparent from a consideration of the following detailed specification.

In the drawings accompanying the specification:

Figs. 1A, 1B, and 1C represent three cutaway views of an illustrative embodiment of the improved crystal rectifier structure;

Fig. 2 represents schematically a parallel plane transmission line including a center conductor which will aid in gaining an understanding of one principle of the invention;

Fig. 3 shows a cat whisker of the prior art having an S bend; and

Fig. 4 shows a cat whisker with a C bend as in the illustrative embodiment.

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Basically, the coaxial cartridge crystal rectifier as shown in the several figures of the drawing comprises a brass conductive outer cylinder 11, a spring wire 14 and center conductor assembly 18 mounted on a molded insulating bead 13 and a semiconductive crystal 15 soldered to the end of the outer conductor 11. The spring wire 14 is held in rigid contact with the surface of the semiconductor by a force-fit of the center conductor 18 and insulating bead 13 within the outer conductor 11.

The impedance of the semiconductive wafer is of the order of 30 to 100 ohms in its high conductance state. The characteristic impedance of the commercial coaxial cables to which the crystal rectifier is to be matched is of the order of 70 ohms. However, it can be shown by calculations of the inductance and capacitance in crystal rectifiers of the prior art, considering the spring wire as a distributed discontinuity in a cylindrical cavity, that the characteristic impedance of the spring wire is of the order of 190 to 270 ohms. (The characteristic impedance Z_0 , considering the spring wire and the outer conductor as a short section of transmission line, is determined by the well known equation

$$Z_0 = \sqrt{L/C}$$

where L is the inductance in micromicrohenries of the spring wire and C is the capacitance in micromicrofarads associated with the spring wire.) Thus, a rather severe impedance mismatch of the order of two to one is evident between the coaxial line and the semiconductive wafer due to the presence of the spring wire in prior art structures. A mismatch of this magnitude may be tolerable at bandwidths heretofore employed, but at the broader bandwidths made possible by present advances in the microwave art, any means for reducing such mismatch is a significant contribution.

If the characteristic impedance of the spring wire as a transmission line could be lowered to 100 ohms or less it could more readily be fed by a coaxial transmission line and more readily terminated by the present types of semiconductor contacts. In accordance with principles of the invention, this impedance is lowered by increasing the distributed capacitance and decreasing the distributed inductance of the spring wire in a novel manner, and at the same time effecting along the axis of the crystal rectifier a smooth, uniform impedance.

There are several ways of increasing the capacitance of the spring wire. One way is to impregnate the cavity surrounding the spring wire with a liquid or semi-solid having a dielectric constant higher than that of air which has a dielectric constant of unity. An impregnant such as castor oil, having a dielectric constant ϵ of 4.7 will increase the capacitance by that factor and will decrease the characteristic impedance of the spring wire by $1/\sqrt{\epsilon}$ or 46 percent of its value in air in accordance with well known transmission line equations. By this means alone, the characteristic impedance of the spring wire is brought down to the vicinity of 100 ohms.

Another way to increase the capacitance is to coat the spring wire with a layer of high dielectric constant material, such as ceramic or varnish. This dielectric layer will serve to keep the signals from spreading away from the spring wire and will also serve to lower slightly the effective impedance of the spring wire structure.

The capacitance can be increased in yet another way by bringing a grounded plane into proximity with the spring wire in the plane of the bend in the cat whisker. Bringing two parallel grounded planes near the spring wire is even more effective. By grounded planes is meant planes at the same reference potential. Adoption of the latter alternative leads to a transmission line of the type shown in Fig. 2 wherein reference characters 21 and 22

represent parallel conductive planes of indefinite extent spaced apart by a distance h , and 23 represents a cylindrical center conductor of diameter d located midway between planes 21 and 22. By a well known formula for characteristic impedance Z_0 of a single wire enclosed between parallel planes at the same reference potential (shown, for example, at "P" on page 326 of Reference Data for Radio Engineers, 3rd edition, published by the Federal Telephone and Radio Corporation), the proper spacing between parallel planes can be determined for a desired impedance. The formula for such a transmission line wherein the ratio h/d is greater than 0.75 is

$$Z_0 = \frac{138}{\sqrt{\epsilon}} \log_{10} \frac{4h}{\pi d}$$

where

ϵ =dielectric constant of the medium between planes,
 h =distance between parallel planes,
 d =diameter of the center conductor measured along a line mutually perpendicular to the parallel planes, and
 π =ratio of the circumference to the diameter of a circle, 3.14159+ approximately.

A table of values determined from the above formula may be developed as an aid in the determination of the spacing desirable for a given coaxial line impedance to be matched as follows:

h/d	$Z_0 \sqrt{\epsilon}$ (ohms)
1.5	39
2	57
3	80
4	98
5	110
10	153

The characteristic impedance for a spring wire of the usual diameter of 0.005 inch and a parallel plane spacing of 0.020 inch ($h/d=4$) will be approximately 100 ohms with air as the dielectric and 46 ohms with castor oil as the dielectric (ϵ for castor oil=4.7). It is evident from the equation that a change in diameter of the spring wire in a direction parallel to the grounded planes will not affect the characteristic impedance at that point and therefore the necessary bends in the spring wire will not produce any points of discontinuity such as would be present in a cylindrical cavity surrounding the spring wire.

A further improvement in characteristic impedance is obtained by decreasing the distributed inductance of the spring wire 14. Fig. 3 shows a typical spring wire of the prior art having what might be termed an S bend. In the drawing reference character 26 designates the center conductor to which the spring wire 14 is welded; 27 represents the double bend in the wire defining the S portion from which this particular spring wire configuration takes its name; and 28 represents the formed tip with which point contact is made to the semiconductive wafer in the complete crystal rectifier. The bend is provided to impart resilience to the spring wire so as to maintain constant pressure on the semiconductive wafer despite ambient temperature changes or shock.

Fig. 4 similarly depicts a C bend 29. The reference characters common to Figs. 3 and 4 denote similar structural parts. The distinction between the two lies in the bend in the spring wire. The overall length of the C bend of Fig. 4 is considerably less than the S bend of Fig. 3. Since it is well known that the inductance of a conducting wire increases as the length thereof, it is obvious that the C bend is less inductive than the S bend. A straight wire, not shown, could be used in the structure, but then the necessary resilience in the wire would be absent and a stable contact could not be maintained with the semiconductive material. Summarizing, the C bend

minimizes the length of the spring wire and hence its self-inductance while retaining the necessary resilient mechanical properties for maintaining a stable contact with the semiconductor surface.

Each of Figs. 1A, 1B and 1C shows a complete crystal rectifier structure illustrative of the principles set forth above. Fig. 1A is a side view of the embodiment in the plane of the C bend of the spring. Fig. 1B is a side view of the structure normal to the plane of the C bend. Fig. 1C is a bottom view of the structure.

The reference characters used are common to the three views of Figs. 1A, 1B, and 1C. Outer conductor 11 may comprise in a single piece of conductive material the coaxial line mating portion 20 with center conductor contact stud 12, internal coaxial line portion 13 into which is inserted the insulating material 13a and center conductor 18, a tapered transition coaxial line portion 24, and the parallel plane transmission line portion 16 in the center of which is mounted the spring wire. The mating portion 20 is of a diameter to mate satisfactorily with conventional coaxial connectors. The internal coaxial portion 13 must be of lesser diameter than mating portion 20 because of the inclusion of the insulating material having a dielectric constant other than unity. The characteristic impedance of a coaxial line varies inversely as the square root of the dielectric constant of the insulating material between conductors, as is well known in the art. For a similar reason, the center conductor 18 is shown of greater diameter than stud 12 to effect the same characteristic impedance for the internal coaxial line portion 13 as for the mating portion 20 in which air is the dielectric. The tapering portion 24 of the coaxial line is discussed below. Parallel plane portion 16 is provided in the spring wire region in accordance with a principle of the invention explained above.

Although the parallel plane slot in the practical embodiment does not have the indefinite extent of the theoretical model, its width is sufficient, considering the dimensions of the spring wire, for practical purposes.

The parallel plane slot 16 may be milled into the outer cylinder as shown in the drawing and the outer portion cut down so that a hollow cylindrical sleeve 17 of conductive material may be force-fitted about the slotted portion of the outer conductor. The provision of sleeve 17 simplifies the fabricating problem of constructing the slot 16 in the outer conductor. Although the sleeve is not essential to the functioning of the parallel-plane transmission line, it continues the shielding effect of the outer conductor for the inner conductor. It may be noted that the spring wire 14 welded to the center conductor is oriented so that the plane of its C bend is in a plane parallel with the parallel sides of the transmission line slot 16. In this way the spring wire is effectively rendered "invisible" electrically, i. e., discontinuity in characteristic impedance along the length of the spring wire is eliminated despite the necessary bends for the purpose of keeping the spring wire resilient. Semiconductive wafer 15 is soldered to the base of the slot 16 and spring wire 14 is pointed to make effective contact with the surface of the semiconductive material in the conventional manner. If desired, sleeve 17 could be provided with a bottom plate and assembled on the outer conductor to enclose the slot completely both on the sides and bottom.

In addition to the features of the spring wire structure previously described, the tapering portion 24 of the coaxial line providing a smooth transition between the center conductor stud and the spring wire is shown at 24 in Figs. 1A and 1B. In this portion the external diameter of the inner conductor is progressively decreased from that of conductor 18 to that of the spring wire 14 while the internal diameter of the outer conductor is correspondingly decreased in a progressive manner to preserve a constant ratio of diameters at all points. Thus, the characteristic impedance is maintained constant in this transition region.

With uniform impedance along the axis of the crystal rectifier, all points of impedance discontinuity are eliminated. Since the undesired reflections in crystal rectifiers of the prior art are due to these discontinuities, reflections are greatly minimized by employing the principles of the present invention. As a consequence, bandwidth capabilities of a device, such as illustrated herein, over the prior art are greatly enhanced.

It is to be understood that the particular embodiment described above is intended to be illustrative only since other embodiments incorporating principles of this invention will be readily apparent to one skilled in the art.

What is claimed is:

1. In a translating device for microwave energy including inner and outer coaxial conductors forming at the one end of said device an open coaxial line portion, insulator means supporting said inner conductor within said outer conductor to form a solid coaxial line portion, spaced parallel conductive side members on the opposite end of said outer conductor defining a slot transverse to an axis of said device, a semiconductive wafer making electrical contact with said side members, and a spring wire supported by the end of said inner conductor within said slot and making rectifying contact with said semiconductive wafer, said spring wire being formed with a curved portion lying in one plane only, the plane of said curved portion being mutually parallel with said parallel side members, and said spring wire and said side members forming together a transmission line of characteristic impedance matching that of said solid coaxial line portion.

2. The translating device in accordance with claim 1 in which the diameter d of said contact wire and the distance h between said side members are determined so as to satisfy the relation

$$Z_0 = \frac{138}{\sqrt{\epsilon}} \log_{10} \frac{4h}{\pi d}$$

wherein Z_0 , the characteristic impedance of said line including said spring wire and side members, equals the characteristic impedance of the solid coaxial line portion of said device, and ϵ equals the dielectric constant of the medium surrounding said contact wire.

3. The translating device in accordance with claim 1 wherein the slot formed between said side members is impregnated with a dielectric material having a dielectric constant other than that of air.

4. The translating device in accordance with claim 1 wherein the contact wire is coated with a ceramic material having a dielectric constant other than that of air.

5. The translating device in accordance with claim 1 and in combination therewith a tapering transition coaxial line portion forming an end of said coaxial line portion and uniformly decreasing in cross-section from said last-mentioned portion to said slot.

6. The translating device in accordance with claim 1 wherein the portions of said side members coextensive with said spring wire are enclosed by a sleeve of conductive material mounted on said side members for electrically shielding said spring wire.

7. In a crystal rectifier having at one end a coaxial line input portion and at the other end a semiconductive wafer and a spring wire having a curved portion, said wire having one end connected to said coaxial portion and the other end making rectifying contact with said wafer, means including, a pair of spaced parallel conductive side members forming a straight-sided cavity on at least two sides for enclosing said spring wire, said side members being mutually parallel with the plane of said curved portion of said spring wire to form a transmission line, and the ratio of the spacing between said parallel side members and the thickness of said spring wire normal to said parallel side members in a particular dielectric material between said last-mentioned side members being such as to effect a characteristic impedance for said spring wire and cavity portion equal approximately to that of said coaxial line portion.

References Cited in the file of this patent

UNITED STATES PATENTS

2,429,823	Kinman et al. _____	Oct. 28, 1947
2,438,521	Sharpless _____	Mar. 30, 1948
2,563,613	Ohl _____	Aug. 7, 1951