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NASA CASE NO. MFS-28282-1

PRINT FIGURE 1

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(NASA-Case-MFS-28282-1) PLANAR THIN FILM SQUID WITH INTEGRAL FLUX CONCENTRATOR Patent Application (NASA) 15 p CSCL 20L

N88-29602

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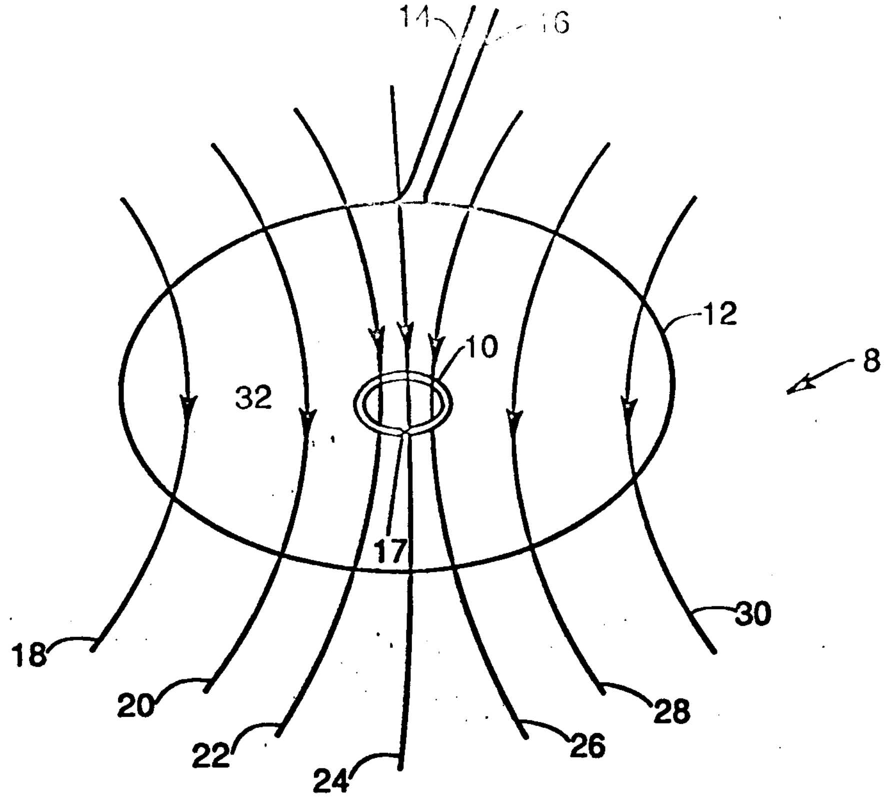

Fig. 1 (Prior Art)

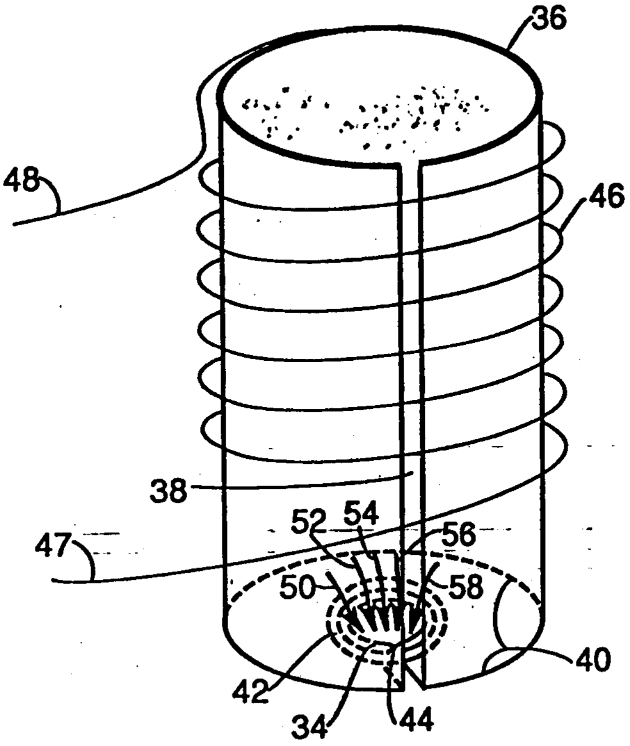

Fig. 2 (Prior Art)

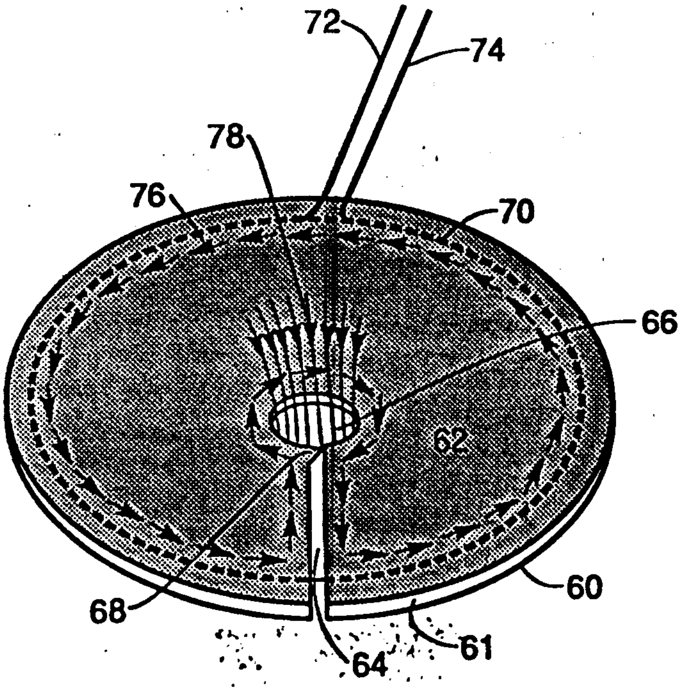

Fig. 3

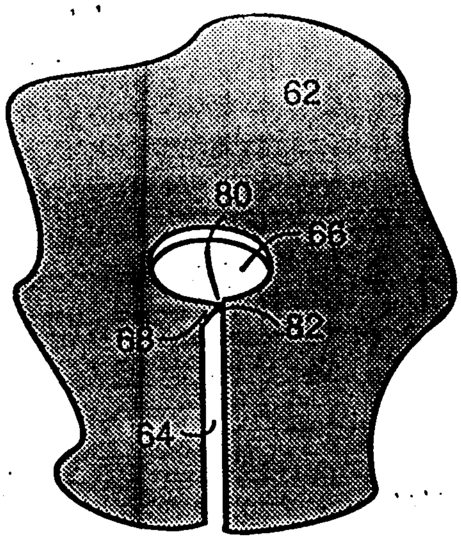

Fig. 4

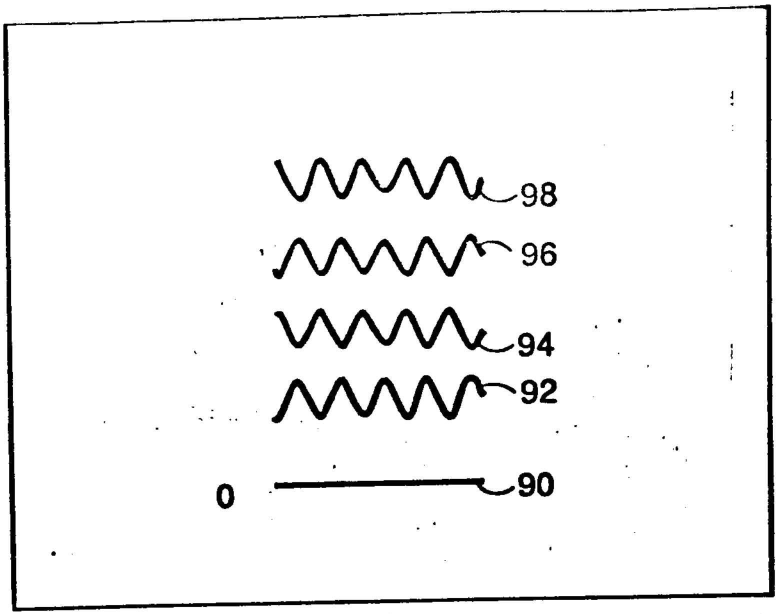
98
96
94
92
0
90

Fig. 5

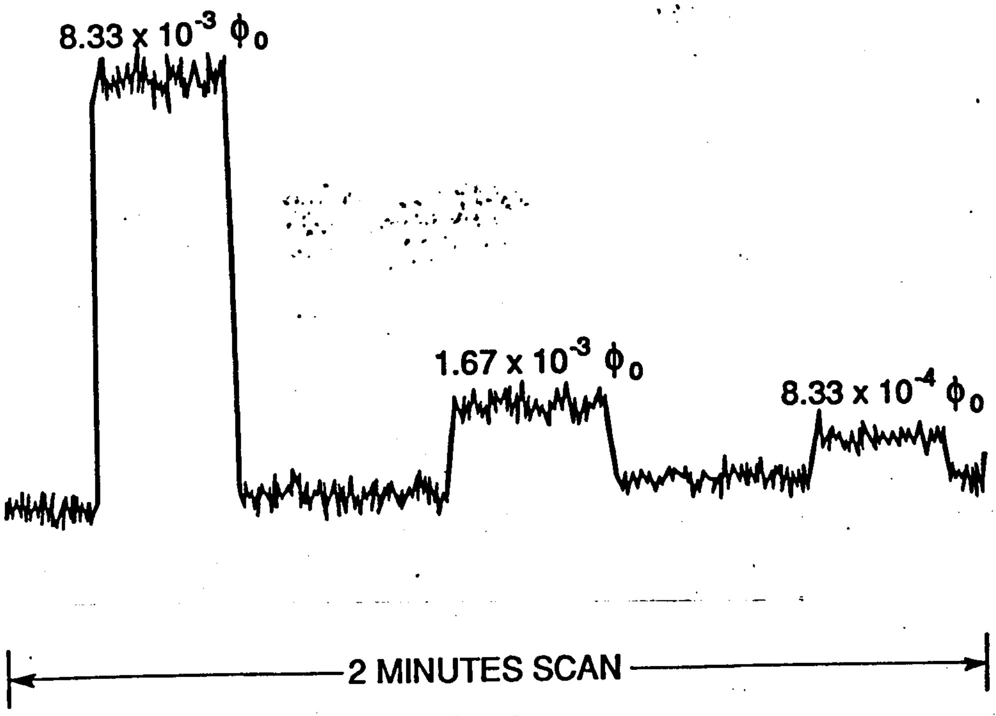
$8.33 \times 10^{-3}\ \phi_0$
$1.67 \times 10^{-3}\ \phi_0$
$8.33 \times 10^{-4}\ \phi_0$
2 MINUTES SCAN

Fig. 6

NASA Case No. MFS-28282-1 PATENT

PLANAR THIN FILM SQUID WITH INTEGRAL FLUX CONCENTRATOR

Origin of the Invention

The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

Background of the Invention

1. Field of the Invention

The invention relates to a superconducting quantum interference device (SQUID), specifically a SQUID of the type that use a Josephson Junction in the superconducting circuit.

2. Description of Prior Art

SQUID is a term used to identify magnetometer type devices which measure extremely low level changes in magnetic fields. It is constructed by interrupting a normally closed loop of superconducting material, typically with a Josephson junction. Closed loop systems are governed by the principles of quantum mechanics for enclosing the flux of magnetic fields in units of discrete quanta. Proper design and construction of the interruption circuit permits measurement of magnetic field changes corresponding to small fractions of a flux quantum passing into or out of the loop. The specific superconducting material may be of two general types. Type I superconductors totally exclude magnetic fields from the interior of the material up to a critical field called HC_1, at which point the material ceases to be superconducting. Type II superconductors also exhibit an HC_1, but still exhibit superconducting properties after magnetic flux begins to penetrate the material in localized regions called flux vortices. Thin films of all superconducting materials tend to exhibit Type II behavior for fields normal to their surfaces. Any flux vortices in films associated with SQUID devices must be strongly pinned to prevent flux motion into or out of SQUID loops except at the Josephson junction. Some materials exhibit sufficiently strong pinning to permit use of planar thin films over a useful range of fields and temperatures.

Numerous SQUID arrays and designs are known in the prior art and many use some type of Josephson junction. A Josephson Junction is the weak link or tiny barrier interrupting the superconductors. It may take many forms including a dielectric barrier on the order of 20 Angstroms thick, a tiny constriction, or a point contact. The prior art SQUIDs using point contact screw mechanisms generally suffer from adjustment and stability problems. Others using thin film devices fabricated on small cylinders frequently experience difficulties with microfabrication. Those using dissimilar metals lack durability in the presence of moisture due to problems with galvanic corrosion. For r.f. SQUIDs to operate effectively, the SQUID inductance must be quite small, on the order of 10^{-9}h, usually requiring either long cylindrical loops of moderately small diameter, larger diameter cylinders in parallel, or very small planar loops. Coupling to the very small planar loops is difficult, generally requiring integral multiturn coils fabricated directly over the SQUID loop, or slotted superconducting cylinders wound with the coupling coil and having a core shape that concentrates the fields inside the SQUID loop. Integral multiturn coils and "hybrid" flux concentrating devices are more complicated in construction and subject to more frequent failure, such as mechanical misalignment of the flux.

It is therefore an object of the invention to enhance the coupling to a planar thin film SQUID through improved flux concentrating and thereby improve its performance.

Another object of the invention is to simplify the manufacture of a planar r.f. SQUID by simplifying its design.

Another object of the invention is to construct a planar r.f. SQUID which is more durable and rugged than the prior art devices.

SUMMARY OF THE INVENTION

The invention starts with a conventional superconducting loop of small inductance having a Josephson junction interrupting an otherwise strong superconducting circuit. The specific Josephson junction proposed has the proper geometry for creating a short narrow junction area in which the weak link provides the phase shifting in the wave function of the supercurrent over a relatively large temperature operating range. The inductive loop is created on a substrate which consists of a simple planar geometry and enables strong coupling of the loop to a simple coil structure, such as a simple wirewound "pancake" coil. A large planar area of Type II superconducting film, exhibiting strong flux pinning, is coated on the substrate such that it surrounds a small open or uncoated area at the center of the SQUID. The superconducting coating essentially excludes magnetic fields up to HC_1 (Meissner Effect) by inducing surface currents in the large planar area. These induced currents exclude flux from the uniformly coated areas and concentrate the flux in the uncoated or open area on the substrate, resulting in stronger coupling of the SQUID to external coils or fields. However, since Type II superconducting films do not totally exclude magnetic flux, strong pinning forces are required in the film material to prevent flux flow into the loop, other than at the Josephson junction.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and additional objects, as well as the various novel features which are characteristic of the present invention, will be understood more clearly and fully from the following detailed description and from the recital of the appended claims, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a end view of a prior art version of a narrow line planar thin film SQUID loop highlighting the typical flux coupling;

FIG. 2 is a second prior art version of a narrow line SQUID with additional external components to increase the flux coupling within the SQUID loop;

FIG. 3 is an inclined view of a preferred embodiment of the present invention showing an integral flux concentrating thin film SQUID having the loop and all related components positioned on a substrate of simple planar geometry;

FIG. 4 is an isolated and enlarged view of the Josephson junction portion of the invention shown in FIG. 3;

FIG. 5 is a graphical representation of the SQUID r.f. detected output vs. audio modulated field for several r.f. inputs;

FIG. 6 is a graphical representation of the SQUID output in the flux locked mode.

DESCRIPTION OF A PREFERRED EMBODIMENT

Two of the prior art systems referred to above are shown in Figs. 1 and 2. In Fig. 1, a narrow line essentially planar SQUID is shown generally at 8 and consists of a washer like SQUID loop 10 surrounded by a multiturn coil 12. The coil 12 is energized through lines 14 and 16 by a conventional r.f. source (not shown). A weakened portion 17 of the SQUID loop 10 provides the needed interruption of the circuit. Flux lines 18-30 indicate the flux coupling when the coil 12 is positioned as shown relative to the SQUID loop 10 and the area 32 between loop 10 and coil 12 is an insulating medium such as air or glass. While alignment of the SQUID loop 10 relative to the coil 12 affects the positioning of the resultant flux field 18-30, the flux concentration within loop 10 is not substantially different from that within open area 32.

Fig. 2 shows a prior method used to concentrate the flux within a superconducting SQUID loop 34. Surrounding SQUID loop 34 is a superconducting cylindrical cup 36 having a slot 38 extending the length of one side and radially into the bottom section 40. At the center of the bottom 40 of the cup 36 is a hole 42, the diameter of which is approximately the same size as SQUID loop 34. SQUID loop 34 not only fits within hole 42 but also is coplanar with the bottom 40 of cup 36. A weakened section 44 of loop 34 provides the needed circuit interruption. Coil 46 is wound around the cylindrical cup 36 and is energized by an appropriate source (not shown) which would be connected to leads 47 and 48 to create lines of flux 50-58 in the direction indicated. As should be apparent, concentrating of flux in this manner requires precisioned machined parts and accurate alignment of the external components.

Fig. 3 shows a preferred embodiment of the present invention which starts with a wafer like substrate 60 having planar geometry. The view is inclined and the dimensions exaggerated to show all of the features of the SQUID. The substrate 60 can be made of quartz, glass or other similar material and has nominal thickness 61, on the order of a millimeter. The substrate diameter is determined by a number of factors including intended use of the SQUID but is generally on the order of millimeters to centimeters. The substrate 60 is coated with a Type II superconducting film, indicated by the shaded portion 62, and is formed with a linear gap 64 in the film extending radially inward to a generally circular area 66 near the center of the substrate 60. The superconducting film 62 may be any suitable Type II superconductor, such as niobium. When niobium is used as the superconducting film, it´s thickness is on the order of 100 nanometers. The gap 64 may be formed by any suitable means such as scratching or etching the substrate 60 after it has been coated with the superconducting film or overlaying the substrate with a mask prior to coating and lifting off the undesired areas with the mask. The area 66 may be a physical hole in the center of the substrate or, more preferably, an uncoated section near the center which serves to form the SQUID loop. The relative dimensions of the respective areas are important to proper operation of the SQUID. For example, the size of the area 66 or SQUID loop diameter determines the inductance of the SQUID and is very small compared to the film coated substrate 62. In addition, the size of the gap 64 is a fraction of the dimension across area 66. The diameter of area 66 typically ranges around 200 micrometers. Within the loop, and located at linear gap 64, is a Josephson junction 68 which bridges the uncoated areas and provides the weakened area in the loop around area 66. A coil 70 is wound on the substrate 60 and attached thereto by any suitable means such as an adhesive or low temperature potting compound. Coil 70 may be a simple wirewound "pancake" coil which is connected to a standard radio frequency (r.f.) source (not shown) by leads 72 and 74. When energized, coil 70 induces currents in planar area of the superconducting film 62 as indicated by arrows 76. Since the superconducting film 62 excludes a magnetic field due to the Meissner effect, the induced currents around the small open loop area 66 act to concentrate the flux lines through that open area, as indicated by arrows 78. By effectively channeling the flux into the small open loop area, the present invention provides greatly enhanced coupling compared to a narrow line loop as shown in Fig. 1, and simplicity of manufacture and alignment as compared to the external bulk flux concentrators of Fig. 2. It should be noted that small superconducting currents also flow across the Josephson junction. The direction of current flow can switch with the difference in phase of the wavefunction across the junction, i.e. from left to right, which contributes to the outer counterclockwise screening portion of the current, or from right to left, which contributes to the clockwise inner portion of the current which is in the SQUID loop.

Fig. 4 shows a magnified and isolated view of a preferred Josephson junction used with the present invention. Using like numbers to indicate the same parts, the superconducting film 62 is shown surrounding gap 64 and the hole 66. A Josephson junction 68 is formed by tapering the superconducting film 62 in the area where the gap 64 meets the hole 66, thus essentially forming a point type contact 80 which is in weak electrical contact with the superconducting film 62 on the opposite side 82 of gap 64. Generally, the Josephson junction will consist of not only a tapered section 68 in the film 62 but also a thinner section of film in that area, especially where the taper meets a thicker area at 82. The thinner section may be a gradual thinning of the film, a single stepped change in film thickness, or an incremental change in thickness. This combination of tapering plus a change in thickness of the superconducting film where the tapered point meets the thicker film area at 82 has proven to provide the desired operation at the junction for the SQUID structure described above.

Figs. 5 and 6 are graphical representations of the measured circuit responses for the present invention. Fig. 5 indicates that the simplified circuit structure of the present invention exhibits typical behavior for r.f. SQUIDs having good coupling. Fig. 6 shows representative noise levels and stability of the SQUID operated in contact with liquid helium at 4.2K, with liquid helium being only one of a number of methods for maintaining temperature in that desired range. More specifically, Fig. 5 shows the changes in r.f. output for the SQUID versus magnetic flux associated with a 1000 Hz sweep. Circuit outputs are indicated by waveforms 90 through 98 for five r.f input levels that produced maximum outputs, beginning with zero r.f. input, represented by straight line 90 and progressing through increasing r.f. inputs 92-98. The difference between peaks on each waveform is equivalent to one flux quantum, i.e. 2.07×10^{-15} weber. Fig. 6 represents an output from commercial magnetometer electronics using a 1 Hz bandwidth and the invention of Fig. 3 operated in the flux locked mode, that is negative feedback is used to cancel the external changes being measured. The peaks 110, 112, and 114 represent the amount of feedback current needed to cancel three levels of externally applied flux, the smallest being 8.33×10^{-4} fraction of a flux quantum, and the peak to peak noise being a fraction of this fraction. Drift due to temperature sensitivity is also seen to be relatively low, when operated in contact with normal boiling point liquid that is not subject to further temperature stabilization.

Thus there has been described a novel planar superconducting quantum interference device, SQUID, designed to be rugged, simple to manufacture, and enhanced in performance. Obviously, other modifications, additions, and variations of the specific embodiment disclosed herein can be constructed or proposed without departing from the true spirit and scope of the invention, as set forth in the following claims.

PLANAR THIN FILM SQUID WITH INTEGRAL FLUX CONCENTRATOR

Abstract of the Disclosure

A thin film SQUID is disclosed having improved flux concentration combined with simplicity of design and fabrication. The SQUID starts with a wafer like substrate having simple planar geometry. A large area of superconducting film is coated on the substrate, with a small open or uncoated area remaining at its center to define a SQUID loop, and a gap in the film formed beginning at the outer circumferential edge of the substrate and extending radially inward to the open area. A Josephson junction is formed across the gap near the open area to interrupt the electrical continuity of the SQUID loop. A coil is attached to the surface of the substrate, electrically insulated from the superconducting film, and is energized to induce flux within the SQUID which is concentrated within the open area.