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[54] **TUNABLE ELECTROACOUSTIC TRANSDUCERS**

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[73] Assignee: **The United States of America as represented by the Secretary of the Navy,** Washington, D.C.

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[52] **U.S. Cl.** ..... **333/72,** 310/9.8, 333/30 R, 357/15, 357/26

[51] **Int. Cl.** **H03h 9/26,** H03h 9/30

[58] **Field of Search** ..... 333/30 R, 72; 330/5.5; 317/235; 310/8.0, 8.1, 9.4, 9.7, 9.8

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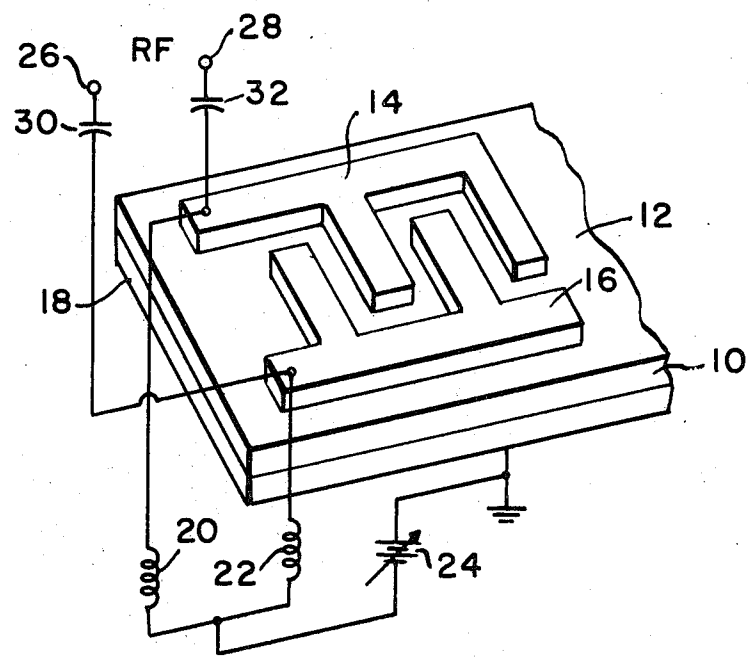
[57] **ABSTRACT**

A plurality of electroacoustic stripe electrodes are formed as a thin film on the surface of a piezoelectric semiconductor slab. The electrode-semiconductor interface forms a varactor junction. By selectively interconnecting the stripes and applying bias voltages, a tunable electroacoustic transducer or UHF filter is achieved.

10 Claims, 8 Drawing Figures



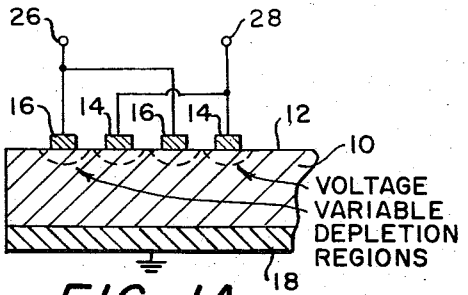


FIG. 1A.

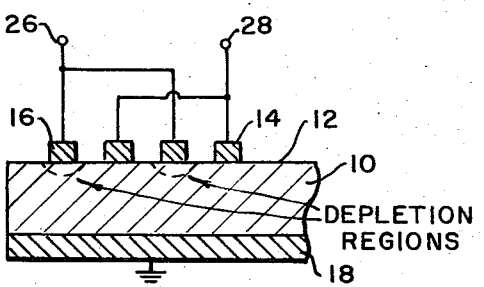


FIG. 2A.

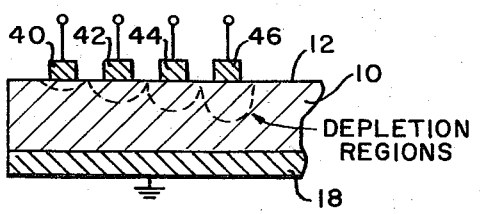


FIG. 3A.

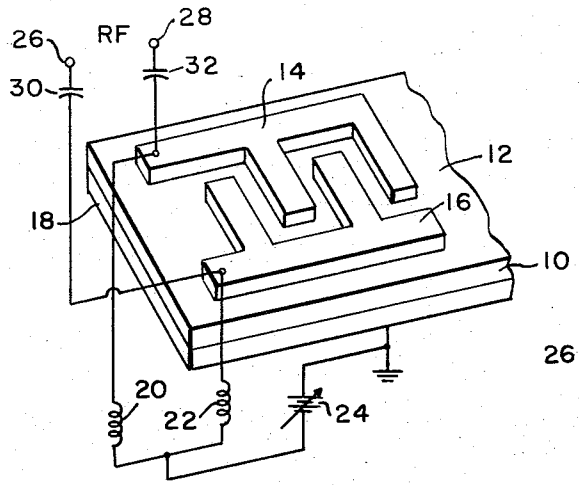


FIG. 1B.

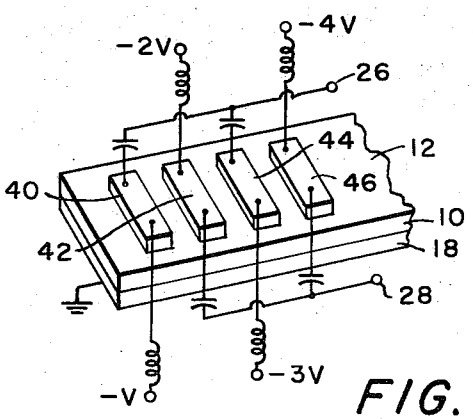


FIG. 3B.

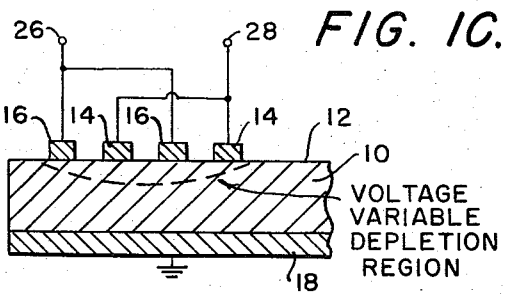


FIG. 1C.

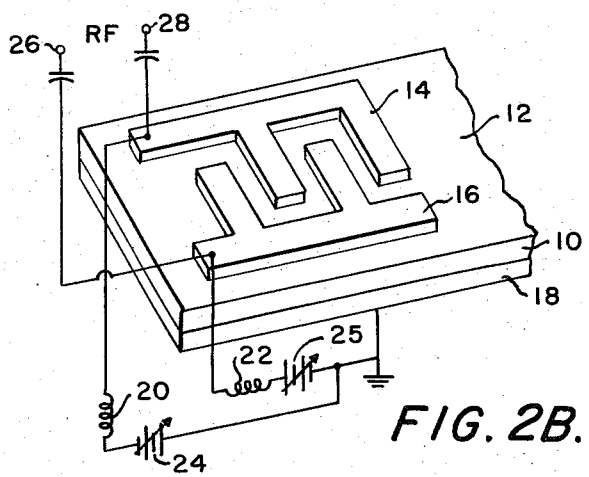


FIG. 2B.

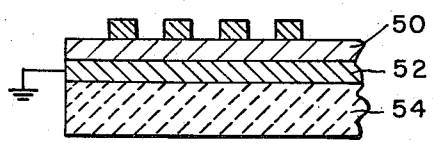


FIG. 4.

TUNABLE ELECTROACOUSTIC TRANSDUCERS

BACKGROUND OF THE INVENTION

The present invention relates generally to the field of electroacoustic transducers and more particularly to interdigital electroacoustic transducers for use with surface acoustic wave devices.

Interdigital electroacoustic transducers find wide use in present day electroacoustic devices. An analysis of the operating characteristics of these devices can be found in the article by Smith et al., *Analysis of Interdigital Surface Wave Transducers by Use of an Equivalent Circuit Model* in Trans IEEE, MIT-17, November 1969. It is known to use these transducers to attain a wave delay effect. See, for example, *Design of Surface Wave Delay Lines with Interdigital Transducers*, by the same authors and with the same citation as the above noted article. The interdigital electroacoustic transducers of the prior art are fixed devices and are not electronically tunable, except possibly by external means in the matching circuitry.

Surface wave filters are also known in the art and are described in an article by Tancrell and Holland, *Acoustic Surface Wave Filters*, Proc. IEEE 59, No. 3, March 1971. These are also fixed devices. In particular, their frequency (periodicity) and band shape (amplitude or phase weighting) are specified by the evaporated metal patterns.

SUMMARY OF THE INVENTION

The present invention makes use of a variable varactor depletion region to electronically control the frequency response and efficiency of an electroacoustic interdigital transducer so that it can function as a tunable transducer or tunable surface acoustic wave filter. The transducer is formed by thin film metallic stripes disposed on the surface of a piezoelectric semiconductor body which forms Schottky barriers. A ground electrode is formed on the opposite surface of the body. By varying the bias voltage applied to the stripes, as a whole or on individual stripes, the depletion region or regions associated with the Schottky barriers vary, whereby the propagation velocity of a surface acoustic wave is varied. By varying the bias voltage on individual stripes in different ways, a number of functions can be accomplished, as will be described below.

Therefore, it is an object of the present invention to provide a surface acoustic wave transducer which can be electronically controlled as to frequency response and efficiency.

Another object of the invention is to provide a surface acoustic wave filter which can be tuned to a plurality of frequencies.

A further object of the invention is to provide a tunable electroacoustic transducer which has an extremely high Q factor.

A still further object of the invention is to provide an interdigital electroacoustic transducer which can be tuned by varying the voltage on the elements of the transducer.

Yet another object of the invention is to provide an electroacoustic transducer which operates by means of a varactor junction.

Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A, 1B and 1C show the invention connected to operate as a surface wave filter.

FIGS. 2A and 2B show the invention connected to operate as a variable conversion efficiency transducer.

FIGS. 3A and 3B show the invention connected to operate as a variable frequency and band shape filter.

FIG. 4 shows an alternative construction of the surface wave propagating body.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 1A through 1C illustrate a preferred embodiment of the invention in which surface wave frequency filtering is achieved. The surface acoustic wave propagating body comprises a crystal of piezoelectric semiconductor material **10**, such as zinc oxide, cadmium selenide, cadmium sulfide, or gallium arsenide. Disposed on one surface **12** of the crystal are interdigital transducer electrodes **14** and **16**. The electrodes comprise stripes of thin film metal such as gold. A ground electrode **18** is disposed on the opposite surface of crystal **10**. The ground electrode may be, for example, a thin film of aluminum. As is well known in the art, the gold film-piezoelectric semiconductor interface results in the creation of a Schottky barrier varactor junction. The depletion depth of the varactor can be controlled by the voltage applied to thin film electrodes. In FIGS. 1A–1C, electrodes **14** and **16** are connected through inductances **20** and **22** respectively to D.C. bias source **24**. The inductances are used to block the RF signal from entering the D.C. source. Connected in this manner, each stripe is at the same D.C. potential which results in similar depletion regions under each stripe as shown in FIG. 1A. If the bias voltage is high enough, the depletion regions will substantially overlap and there will be effectively one depletion region. This effect is illustrated in FIG. 1C. The electrodes are connected to an RF source via terminals **26** and **28**. Capacitors **30** and **32** are placed on the RF line to isolate the D.C. from the RF source.

The device of FIGS. 1A–1C achieves tunable surface wave filtering. The D.C. bias applied to the electrodes causes a near uniform depletion region to exist below the interface. As is well known in the art, the velocity of propagation of a surface wave can be changed by bringing a conducting plane into close proximity to the surface of the piezoelectric medium. In the device of the present invention, conducting ground plane electrode **18** is brought effectively closer or further from the surface **12** of crystal **10** from within the crystal by changing the depth of the depletion regions under the D.C. biased stripes. The depth of the depletion region depends on the amplitude of the applied D.C. bias. Therefore, varying the D.C. bias varies the propagation velocity of the surface acoustic wave (introduced on RF terminals **26** and **28**) under the metal stripes and between them in the situation of FIG. 1C. Since the stripes are a fixed distance apart, varying the surface wave propagation velocity varies the frequency of the filter.

Referring now to FIGS. 2A and 2B, the device is connected so as to function as a variable conversion efficiency transducer. The only difference between these figures and FIGS. 1A–1C is the electrical connections. As shown specifically in FIG. 2B, D.C. bias source **24** is connected only to electrode **14.** A small positive potential is applied to electrode **16** by D.C. source **25.** This small positive potential is used to quench the small depletion region which exists at zero bias at a metal-semiconductor interface. This type of connection, wherein the depletion regions under the stripes are alternately reinforced and quenched, results in the situation illustrated in FIG. 2A. Since only alternate stripes have depletion regions under them, the variable depletion regions do not change the frequency of the transducer. Instead, the high resistivity area under the biased stripes is varied resulting in variable conversion efficiency.

Referring to FIGS. 3A and 3B, the device shown is a variable frequency and band shape filter. In this embodiment, individual stripes **40, 42, 44** and **46,** each comprised of a thin film of metal, are used in place of the interdigital type electrodes of FIGS. **1** and **2.** This is done so that each individual stripe can be biased differently. As shown in the figure, stripes **40, 42, 44** and **46** are biased at voltages V, 2V, 3V and 4V respectively. This results in there being a different depletion region depth under every stripe. This effect is illustrated in FIG. 3A which shows the depletion region depths varying progressively along the crystal in accordance with the D.C. bias applied to the stripes. By varing the resistivity, and therefore the conversion efficiency, under individual stripes, amplitude weighting is achieved and a band shape filter results.

FIG. **4** shows an alternative structure for the propagating device. In this embodiment, a thin film piezoelectric semiconductor **50** is used as the propagating medium instead of crystal **10.** A thin film ground plane **52** is disposed adjacent the semiconductor film **50.** The ground plane and piezoelectric semiconductor film are deposited on a substrate **54** of insulating material such as glass. This embodiment has the advantage that the expensive and relatively temperature sensitive piezoelectric semiconductor crystal is replaced by an inexpensive and stable substrate. The embodiment of FIG. **4** operates in all respects the same as the embodiments previously described. The metal stripe structures and the D.C. biasing techniques of FIGS. **1–3** are equally applicable to the FIG. **4** structure.

Although only Schottky barrier devices have been discussed, any type of junction varactor may be utilized. However, with the present state of the art, they do not appear to be as useful as the Schottky barrier varactors since high quality semiconductor material cannot be deposited as thinly as metal and the thickness of the semiconductor material is significant in comparison to the size of the surface wave. However, advancements in technology may render other junction devices more valuable in the future.

Obviously many modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed and desired to be secured by Letters Patent of the United States is:

1. An electroacoustic surface wave device which comprises:

a body of piezoelectric semiconductor material;

a ground electrode disposed on a first surface of said material;

a plurality of metal stripes disposed parallel to one another on a second surface of said material, said first and second surfaces being parallel, whereby a plurality of Schottky barriers are created at the metal stripe-semiconductor interfaces;

means connecting alternate stripes to a first terminal;

means connecting the other stripes to a second terminal, said terminals providing connections for creating an acoustic surface wave in said pizoelectric material; and,

means for controlling the depth of the depletion regions associated with said Schottky barriers.

2. The device of claim **1** wherein each of said metal stripes comprises a thin film of metal.

3. The device of claim **2** wherein said controlling means comprises at least one source of D.C. bias voltage connected to said metal stripes.

4. The device of claim **3** wherein the same source of D.C. bias voltage is connected to every metal stripe, whereby a substantially uniform depletion region exists in said semiconductor material under and between said stripes.

5. The device of claim **3** wherein each metal stripe is connected to a different source of D.C. bias voltage.

6. The device of claim **2** wherein said body of piezoelectric semiconductor material is a crystal.

7. The device of claim **6** wherein said body of material is a cadmium sulfide crystal.

8. The device of claim **2** wherein said body of piezoelectric semiconductor material comprises a thin film of piezoelectric semiconductor material deposited on a substrate.

9. The device of claim **8** wherein said substrate is glass.

10. An electroacoustic surface wave device which comprises:

a body of piezoelectric semiconductor material;

a ground electrode disposed on a first surface of said material;

a plurality of thin film metal stripes disposed parallel to one another on a second surface of said material, said first and second surfaces being parallel, whereby a plurality of Schottky barriers are created at the metal stripe-semiconductor interfaces; and,

means for controlling the depth of the depletion regions associated with said Schottky barriers, said means comprising a single source of D.C. bias voltage connected to alternate metal stripes and another D.C. source of proper polarity connected to the other stripes to quench the depletion region under said other stripes.

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