

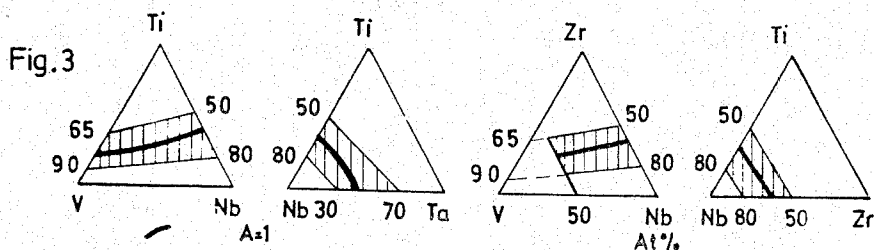
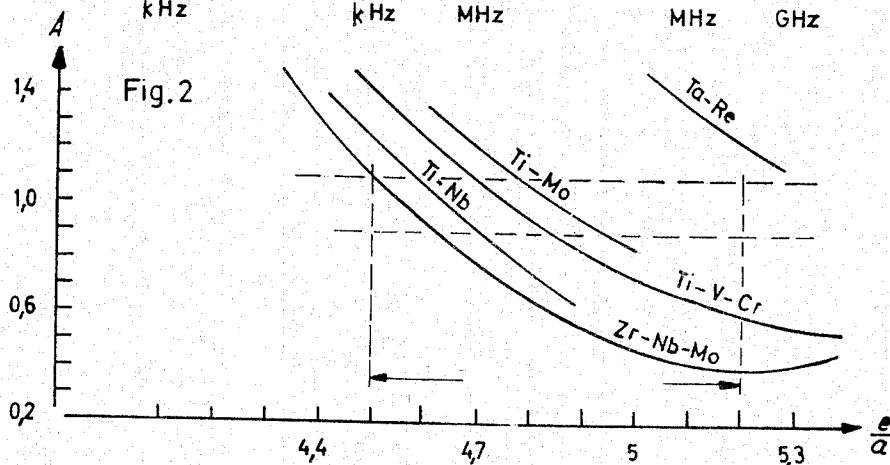
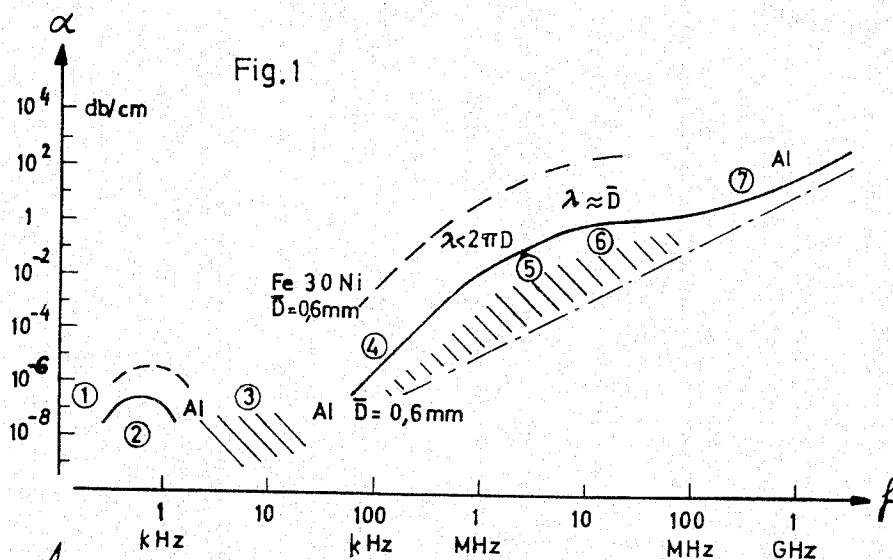
Aug. 14, 1973

S. STEINEMANN

3,752,664

METALLIC SOUND CONDUCTOR OR SOUND RADIATOR

Filed Oct. 27, 1970



INVENTOR:

SAMUEL STEINEMANN

BY *McGraw and Toren*
ATTORNEYS

1

3,752,664 METALLIC SOUND CONDUCTOR OR SOUND RADIATOR

Samuel Steinemann, Liestal, Switzerland, assignor to
Institut Dr. Ing. Reinhard Straumann AG, Waldem-
burg, Switzerland

Filed Oct. 27, 1970, Ser. No. 84,308
Claims priority, application Switzerland, July 13, 1970,
10,571/70

Int. Cl. C22c 1/00

U.S. Cl. 75—134 N

6 Claims

ABSTRACT OF THE DISCLOSURE

A metallic sound transmitter or sound radiator combines the low attenuation of a polycrystalline material with the malleability of a metal. The attenuation coefficient is seen to be determined by sound scattering in polycrystalline metals as a consequence of elastic anisotropy which in turn is determined by an electronic property in an alloy, so that a low coefficient can be obtained by providing alloys of predetermined composition which have the appropriate electron per atom ratio.

FIELD OF INVENTION

The present invention relates to a sound conductor and, more particularly to a metallic low-loss sound conductor or sound radiator.

BACKGROUND OF THE INVENTION

In delay lines which are of great importance for telecommunication, data processing, computers, measuring devices, and the like, an electric signal is transformed into a sound wave by piezoelectric, magnetostrictive or other transducers. The sound wave propagates as an elastic longitudinal or shear wave through a sound transmitter which may be a rod, a band or a wire. Subsequently another transducer re-transforms the sound wave into an electric signal of predetermined delay time. Conventional sound transmitting media are glasses, mercury, aluminum alloys, nickel or temperature-compensating alloys such as Ni-span etc. The characteristics of such materials must include low attenuation, homogeneity, the lowest possible temperature coefficient of a wave velocity, low propagation velocity in order to permit a compact design, and possibly a high coupling factor for magnetostrictive excitation and detection. The totality of these requirements can be attained only to a limited extent.

Low-loss materials for sound transmitters are also required in ultrasonics, for the processing of hard materials, for material testing, for echo sounding devices and so on. Sound transmitters for such purposes are at present made of anticorodal, brass, titanium alloys and so on.

2

In polycrystalline materials the propagation velocities of the longitudinal waves

$$v_L = \sqrt{E/\rho}$$

and of the shear waves (or transverse waves) it is

$$v_T = \sqrt{G/\rho}$$

where E is the bulk modulus of elasticity, G is the shear modulus of elasticity and ρ the density. The attenuation α is represented as a loss of energy over the propagation distance; it is related to the known quality factor Q of an oscillator through the relation

$$Q = \frac{p^2 - \alpha^2}{2\alpha p} \approx \frac{p}{2\alpha} \text{ for } p = \frac{2\pi f}{v}$$

where f is the frequency and p the phase shift constant in radians/cm.

Typical values for three well-known materials are shown in Table I.

TABLE I

Material	v_L (m/s)	v_T (m/s)	Temperature coefficient (degree ⁻¹)	α Attenuation (db./cm.)
SiO ₂ amorph.....	6.10 ³	3.8.10 ³	1.10 ⁻³	3.10 ⁻³ (transversal 30 mHz.).
Ni.....	4.8.10 ³	3.10 ³	15.10 ⁻³	6.10 ⁻² (longit. 2 mHz.). 6.10 ⁻¹ (transverse 2 mHz.).
Ni-span C.....	4.5.10 ³		Adjustable	1.5.10 ⁻¹ (longit. 2 mHz.).

It is seen from Table I that, in contrast to metallic sound transmitters, quartz has an extremely low attenuation. However, quartz cannot be fashioned into various shapes such as are often required; for delay lines quartz is conventionally used in the form of a rod or a polygon. Metallic sound transmitters, on the other hand, can be given any desired shape. Metals also have greater resistance to fatigue; this is an important consideration in sound conductors which must transmit high interstices of sound. The advantages are offset, however, by the greater sound attenuation in metals.

It is, therefore, an object of the present invention to overcome the drawbacks of prior art by providing a metallic sound transmitter which combines the desirable sound transmitting properties of amorphous quartz—that is, low attenuation—with malleability which permits any desired shape of a sound conductor, and with a low temperature coefficient of elasticity, that is of the wave velocity.

Another object is to provide a metallic sound transmitter of low propagation velocity which permits compact design.

A further object is to provide a metallic sound transmitter of great strength and stability.

SUMMARY OF THE INVENTION

The objects and others which will become apparent hereinafter are attained, in accordance with the present invention, by an elastically isotropic sound transmitter which is made of one of a number of metal alloys.

The attenuation of sound is minimum in elastic isotropic substances such as amorphous (amorphous=isotropic) quartz, but metals which always occur in crystalline form are, with very rare exceptions, anisotropic. It has been found that in certain alloys the anisotropy coefficient of the metallic components is related to the electron concentration, that is to the ratio of free electrons to atoms in the alloys. The sound transmitter according to the invention is formed of several alloys whose electron concentrations correspond to an anisotropy coefficient of 1. This implies that the sound wave propagates with equal velocity in all directions and losses because of the randomly oriented grain structure in polycrystalline metals as obliterated.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present invention will become more readily available from the following description, reference being made to the accompanying drawing in which

FIG. 1 is a diagram which shows the attenuation α of sound as a function of the frequency f .

FIG. 2 is a diagram which shows the anisotropy factor A of a number of alloys as a function of the electron per atom ratio e/a ; and

FIG. 3 includes four diagrams showing curves corresponding to $A=1$ for various alloys.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Over a wide range the attenuation of sound in solids is a function of the frequency and some of the losses are related to the elastic anisotropy of the material. FIG. 1 shows the relation between frequency and attenuation for aluminum (solid curve) and a Fe 30 Ni alloy (dashed curve). The grain diameter of either material is $D=0.6$ mm. The data were obtained for longitudinal sound waves, but the attenuations for transverse waves are in the same order.

The following phenomena are typical for the different frequency regions:

Region (1)—That is roughly below 1 kHz.: Relaxation phenomena of interstitial atoms in solution, dislocation motions, low attenuation.

Region (2)—between 1–10 kHz.: Thermoelastic relaxation loss in polycrystalline substances of Zener effect. In a polycrystalline material the randomly oriented elastically anisotropic grains are homogeneously compressed and dilated which results in different local temperatures and relaxation loss due to heat flow.

Region (3)—moderate frequencies: Relaxation phenomena due to dislocation motions and interactions between chemical and structural lattice defects; in general attenuation is low, except in ferromagnetic materials.

Regions (4), (5) and (6): Sound scattering and sound diffusion in polycrystalline material, due to the fact that in those substances the randomly oriented elastically anisotropic grains do not have identical sound impedance so that sound is scattered (like light) or diffused by reflection. The effects are distinct when the wave length $\lambda=v/f$ is of the same order of magnitude as the means diameter $\bar{D}$ of the crystal, respectively of the grain (4) is carried the Rayleigh region, (5) the intermediate region, and (6) the diffusion region. In the three regions the attenuation depends on parameters like the average diameter of grains, on the frequency and on the elastic anisotropy coefficient.

In region (7) which includes still higher frequencies there is hysteresis loss and thermoelastic relaxation; the latter varies as the second power of the frequency. Its absolute value is determined by the specific heat and thermal conductivity of the material.

The rapid increase of the attenuation in the regions (4) and (5) limits the potential use of metal for delay lines. The larger the individual grains of a polycrystalline

substance, the greater the attenuation in these frequency ranges. Although the technology of cold working and special heat treatments can produce grains of very small size, the effective limit for delay lines remains at approximately 2 mHz. which is unsatisfactory insofar as higher frequencies would increase the volume of information amenable for such devices.

The attenuation in the regions (2), (4), (5) and (6) is a function of the elastic anisotropy of the material. (For a theory of the relation see C. Zener "Elasticity and Anelasticity of Metals," the University of Chicago Press, Chicago-London 1948; W. P. Mason: "Physical Acoustics and the Properties of Solids," D. Van Nostrand Company, Princeton-Toronto-London-New York, 1958; R. T. Smith and R. W. B. Stephens: "Effects of Anisotropy on Ultrasonic Propagation in Solids," edited Standford, Fearson and McGonnagle "Progress in Applied Materials Research", vol. 5, pp. 41–64, 1964, Heywood Book Temple Press Book London.

As described heretofore, elastically isotropic metals are not known (tungsten, though elastically isotropic, has a high density and is moreover not suitable as a construction material). Aluminum, as shown in FIG. 1, has an attenuation which increases with increasing frequency and an anisotropy coefficient $A=1.23$; for the Fe 30 Ni alloy of FIG. 1 (and for Ni-span) $A=3.08$. The value

$$A = \frac{CS}{CP} \text{ for } CS = C_{44} \text{ and } CP = \frac{1}{2}(C_{11} - C_{12})$$

is obtained through measurements of a single crystal (and under certain assumptions, of a polycrystalline substance) where CS and CP are the independent shear moduli. The equation $A=1$ implies that the sound waves propagate equally in all directions, so that there is a smooth transition between the boundaries of grains of different orientation. In other words, the impedance of the grain boundaries vanishes.

It has been found that in transition metals and in certain regions of the alloys of these metals one of the two independent shear moduli, namely CS , can be substantially reduced by the free metal electrons. Normally A is between 2 and 10 but the contribution of the band structure of the metal to CS lowers A to 1, or even less, for certain ranges of the electron per atom ratio. The description in terms of electrons is a physical reality in view of the nature of the phenomena.

FIG. 2 shows the results of systematic measurements of the anisotropy factor A as a function of the ratio of free electrons per atom e/a (also called the electron concentration) of various alloys.

The ratio is

$$e/a = 1/100 \sum_i X_i V_i$$

and is determined for an alloy by multiplying the concentration in atom percent V_i by the number of outer electrons (group number in the Periodic System) V_i for each of the components, and summing the products. It appears that anisotropy can be represented by the ratio e/a uniformly, that is independently of the components, as a band contribution to the elasticity; thus the so-called "rigid band model" is valid for the anisotropy factor, provided that the band contribution is high which shows, for example, in a high magnetic susceptibility of more than $50 \cdot 10^{-6}$ EME/mol or in a high specific heat at low temperatures.

A metallic sound conductor or sound radiator, according to the present invention, comprises an alloy in which the electron per atom ratio e/a lies between 4.4 and 5.2, preferably between 4.5 and 4.9. At least 70% of the atoms, and advantageously up to 90% of the atoms of the alloys which are contemplated, are selected from the elements of groups IV, V and VI of the transition metals. It is particularly advantageous to include an alloy in a single-phase state. Suitable components are thus Ti, V, Cr, Zr, Nb, Mo, Hf, Ta and W.

The following tabulation shows several alloys according to the present invention, together with their e/a values. The percentage values always refer to atom percent. The anisotropy factor $A=1$ for the alloys corresponds to isotropic alloys with proportionally low attenuation.

(a) $e/a=4.78$:	Percent
V	78
Ti	22
(b) $e/a=4.6$:	
Nb	60
Zr	40
(c) $e/a=4.65$:	
Nb	65
Ti	35
(d) $e/a=4.78$:	
Ti	61
Cr	39
(e) $e/a=4.88$:	
Ti	56
Mo	44
(f) $e/a=4.62$:	
Nb	62
Zr	28
Ti	10
(g) $e/a=4.7$:	
Nb	50
V	20
Ti	30
(h) $e/a=4.8$:	
Nb	70
Ta	10
Ti	20
(i) $e/a=4.6$:	
Nb	50
V	10
Zr	40
(k) $e/a=4.65$:	
Nb	25
V	40
Zr	25
Ti	10
(l) $e/a=5.00$:	
Nb	60
Ta	40
(m) $e/a=4.8$:	
Ti	60
W	40
(n) $e/a=5.1$:	
Nb	50
Ta	40
Mo	10
(o) $e/a=4.7$:	
Nb	40
V	30
Ti	30
(p) $e/a=4.78$:	
Ti	74
Mn	26
(q) $e/a=4.8$:	
Ti	80
Fe	20
(r) $e/a=4.84$:	
Ti	50
Cr	44
Al	6

FIG. 3 shows additional examples for ternary alloys. The solid lines in the shaded areas, that is in the regions of the contemplated alloys, represent those alloys for which $A=1$.

The Examples (p) and (q) in the above tabulation include components selected from elements which are outside of the groups IV, V and VI, and Example (r) even includes a non-transition element. Such elements

(as for example Al, Cu) increase the mechanical strength but apparently suppress the band contribution to the moduli of elasticity, so that their concentration is to be less than 10%.

Measurements of the sound data for several alloys according to the present invention are shown in the following Table II:

TABLE II

	a	b	c
v_L (m/s).....	$4.5 \cdot 10^3$	$3.5 \cdot 10^3$	$3.5 \cdot 10^3$
v_T (m/s).....	$3 \cdot 10^3$	$2.5 \cdot 10^3$	$2.5 \cdot 10^3$
Temperature coefficient of v_L (degree $^{-1}$).....	$-10 \cdot 10^{-5}$	$-3 \cdot 10^{-5}$	Small
α (Longit., 10 mHz.) (db./cm.).....	10^{-3}	10^{-3}	10^{-3}

The shaded area of FIG. 1 represents the attenuation values of the inventive elastically isotropic alloys which are $1/10$ to $1/1000$ of the attenuation values of traditional anisotropic metals. Furthermore, the sound propagation velocity in these alloys is lower, so that shorter lines can be used for any desired delay time.

Since the compressions and dilations of a polycrystalline structure are uniformly distributed throughout the elastically isotropic material, its fatigue resistance has an optimum value. In anisotropic metals, on the other hand, differential stressing of the grains results in stress peaks which in turn destroy the crystal lattices by local cracks.

In delay lines, sound conductors according to the present invention are preferably used in the form of cylinders or wires. Excitation and detection of the acoustic oscillations is effected through piezoelectric or magnetostrictive transducers.

In ultrasonic devices for the processing of hard materials, for material testing or for sonars, the isotropic alloys are used in the form of cylinders or horns.

The alloys are produced by smelting the component elements in an arc furnace or an electron beam furnace and subjecting them to traditional processing by forging, extruding rolling, drawing (either hot or cold) and heat treating. Unavoidable fluctuations of the concentrations are relatively insignificant because the anisotropy constant A varies only slowly with the ratio e/a .

Several of the alloys (for example V-Ti, Nb-V-Ti) exist only in the β -phase subject to certain conditions. Others exhibit the β -phase only at elevated temperatures but decompose for a multiphase structure at temperatures below $500-800^\circ \text{C}$. (for example Nb-Zr, Nb-V-Zr, Ti-Cr). It is thus possible to produce materials of very high strength (by annealing, quenching and precipitation heat treatment) without substantially impairing the attenuation properties because the dimensions of the precipitations are in the submicroscopic range.

What is claimed is:

1. A metallic sound conductor made from an alloy, said sound conductor having each of the following characteristics:

(a) it has an oblong shape;

(b) it is malleable;

(c) it is elastically isotropic;

(d) it consists essentially of an alloy of transition metals, at least 70 atom percent of said transition metals being selected from the transition metals of Groups IV, V and VI of the Periodic Table, and

(e) said alloy having an electron concentration (e/a) in the range of 4.4-5.2.

2. The metallic sound conductor as defined in claim 1, wherein said ratio e/a is in the range 4.5-4.9.

3. The metallic sound conductor as defined in claim 1, wherein said alloy comprises at least 99 atom percent of elements selected from the transition metals of Groups IV, V and VI of the Periodic Table.

4. The metallic sound conductor as defined in claim 1, wherein said alloy further comprises an amount of non-transition metals, said amount being at most 10 atom percent.

5. The metallic sound conductor as defined in claim 1, wherein said alloy comprises up to 30 atom percent of elements selected from the transition elements of Groups VII and VIII of the Periodic Table.

6. The metallic sound conductor as defined in claim 1, wherein said alloy is in single phase condition.

References Cited

UNITED STATES PATENTS

3,298,777 1/1967 Brixner ----- 75—134 S X
3,547,713 12/1970 Steinemann et al. -- 148—11.5

10

3,416,917 12/1968 De Sorbo ----- 75—134 V X
3,582,324 6/1971 Kunert ----- 75—134 S

FOREIGN PATENTS

599,180 5/1960 Canada ----- 75—134 V

L. DEWAYNE RUTLEDGE, Primary Examiner
J. E. LEGRU, Assistant Examiner

U.S. Cl. X.R.

75—134 V, 174, 175.5