June 12, 1962 F. E. VINAL ETAL 3,038,860

LITHIUM NICKEL FERRITES

Filed Dec. 20, 1956 4 Sheets-Sheet 1

Fig. 1

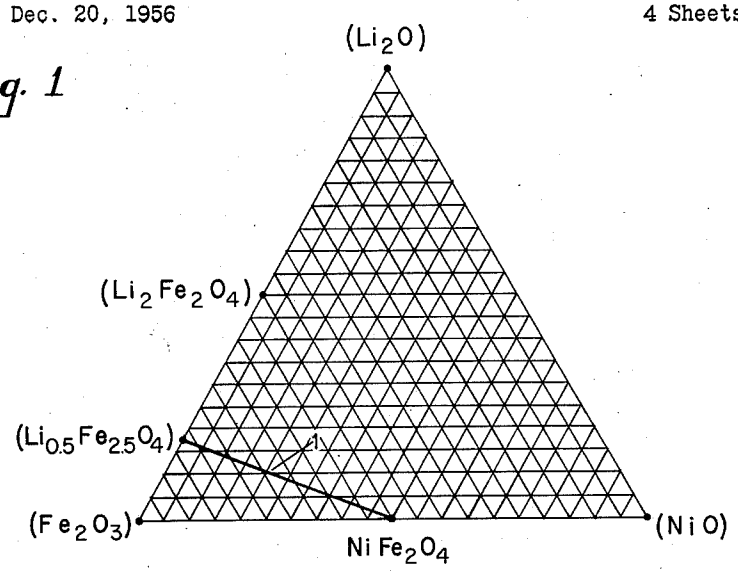
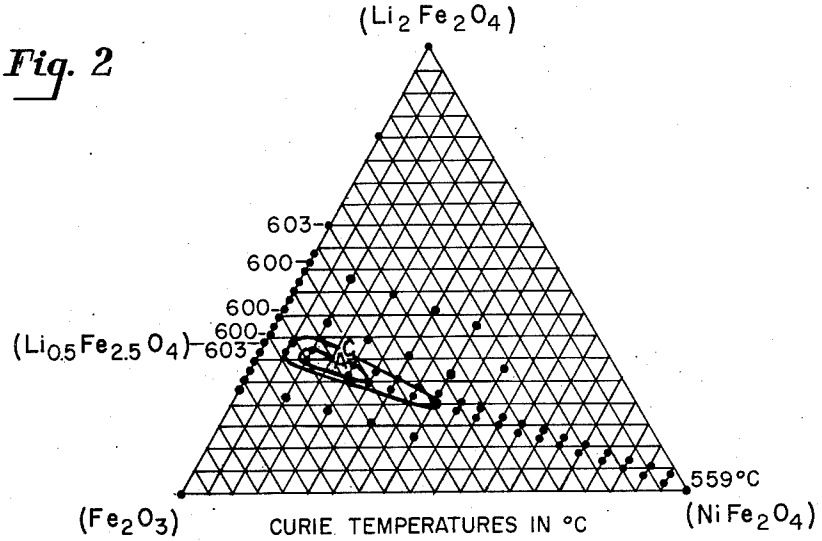


Fig. 2



CURIE TEMPERATURES IN °C
AND
SQUARENESS RATIO CONTOURS

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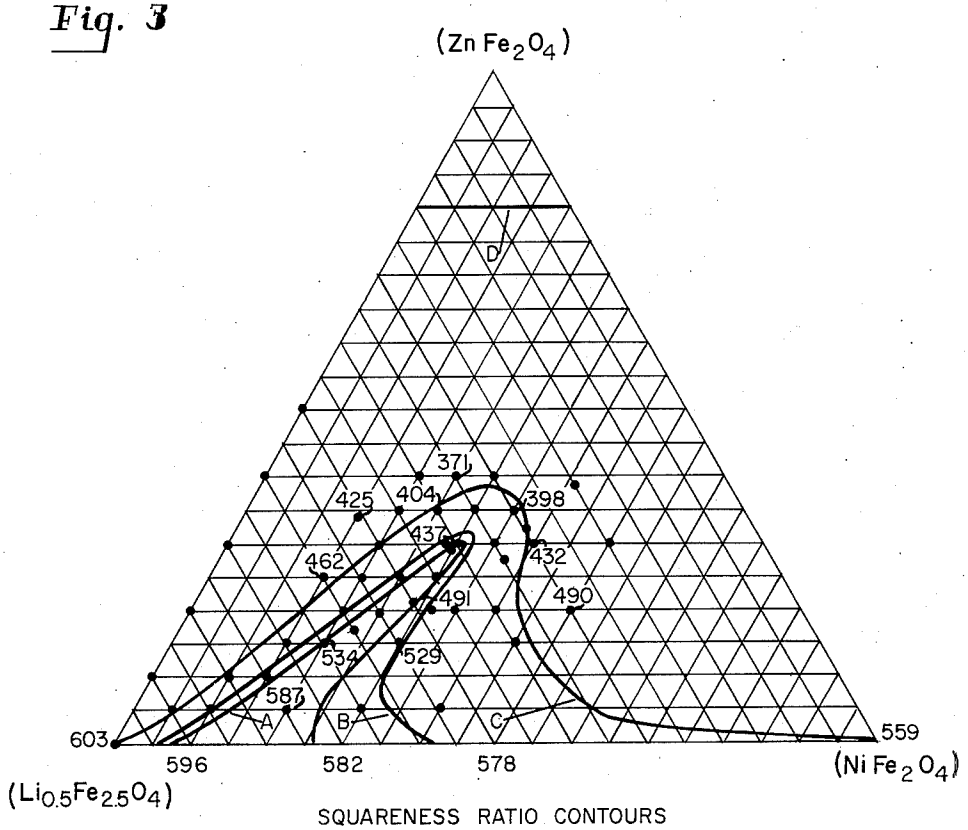
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LITHIUM NICKEL FERRITES

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Fig. 3



SQUARENESS RATIO CONTOURS
AND
CURIE TEMPERATURES IN °C

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LITHIUM NICKEL FERRITES

Filed Dec. 20, 1956 4 Sheets-Sheet 3

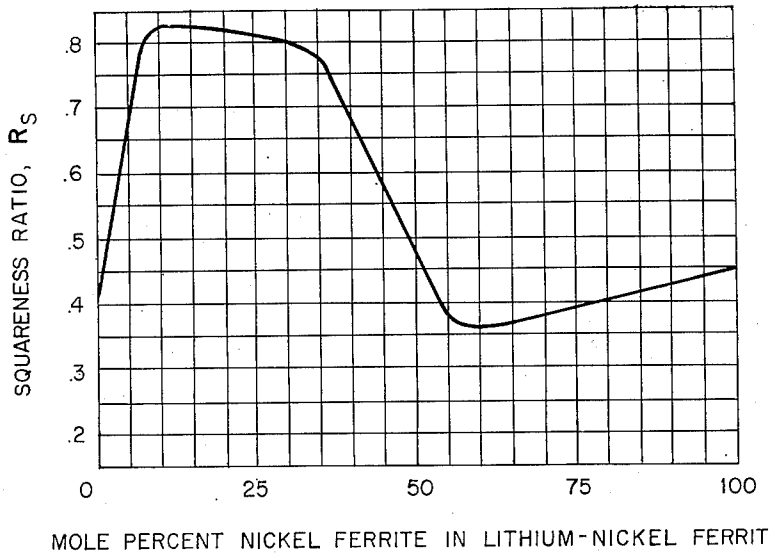


Fig. 4

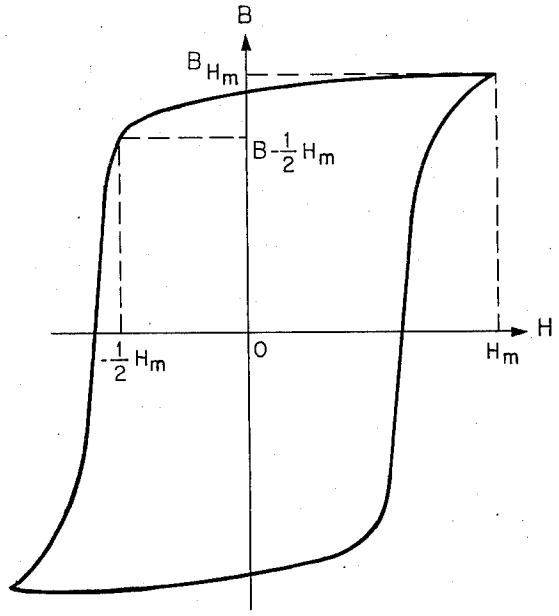


Fig. 5

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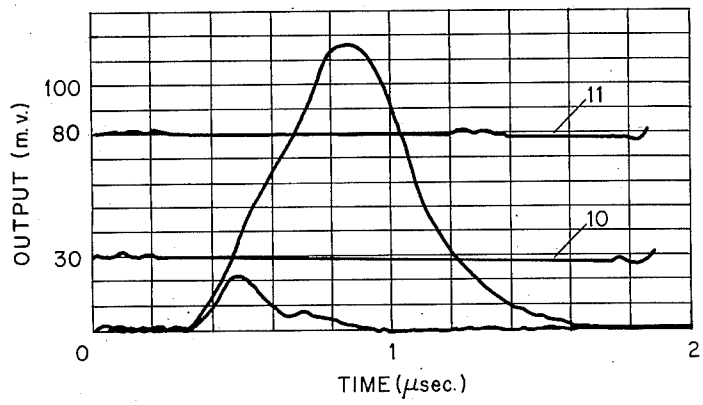
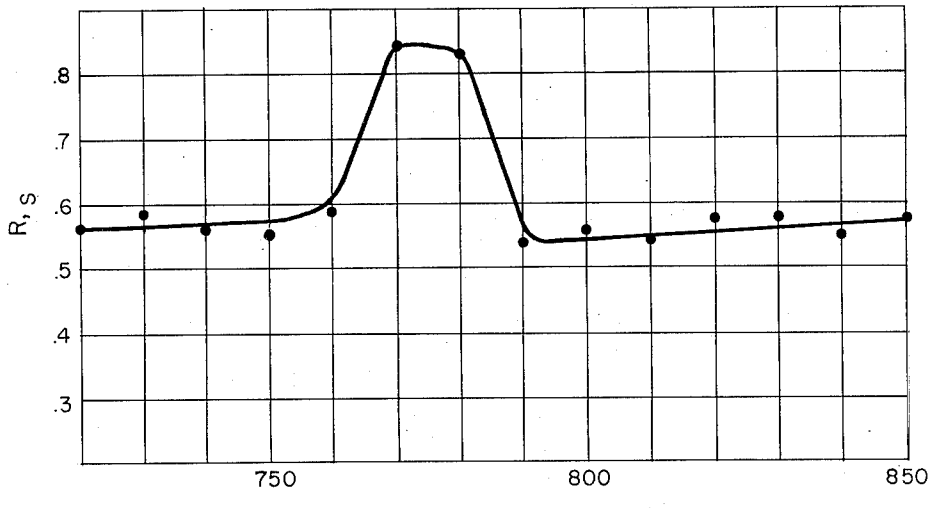


Fig. 6



CALCINATION TEMPERATURE vs. SQUARENESS RATIO, R_S
(Lithium - Nickel Ferrite)

Fig. 7

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LITHIUM NICKEL FERRITES

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Filed Dec. 20, 1956, Ser. No. 629,666
6 Claims. (Cl. 252—62.5)

This invention relates to a process for manufacturing ferromagnetic ceramic products and to the products so produced. More particularly, this invention relates to improved materials of the class known as ferrites, composed of spinel compounds formed from the oxide group including lithium oxide, nickel oxide, iron oxide, zinc oxide and cadmium oxide. Ferromagnetic ceramic bodies have wide technical applications, two examples for bodies having hysteresis loops of substantially rectangular shape being switching arrays and multi-coordinate memory devices for use in the computing field. Ferrite cores with usable properties are now available, the cores normally being formed from compositions containing compounds of manganese, magnesium and iron.

Magnesium-manganese ferrite cores posses a Curie temperature in the vicinity of 250° C., such that elevated ambient operating temperatures must be avoided, yet the cores normally have high coercive forces resulting in the requirement of comparatively high driving currents to alter their magnetic state. Such conflicting requirements have been met in part by air cooling and close temperature control. The materials of the present invention have been found to possess improved magnetic properties, i.e. a higher Curie temperature in the order of 600° C. and with substantially rectangular hysteresis loops. Thus, products made from the materials of this invention can be used at higher ambient temperatures or, more important, with higher energy dissipation than heretofore. The coercive force is approximately the same as that of materials in present use, being somewhat higher or somewhat lower depending upon which of the compositions disclosed is employed.

In some applications ferromagnetic ceramic bodies which have high saturation flux densities, but not necessarily rectangular hysteresis loops, are desirable. Magnesium-managanese ferrites have been modified by additional elements to increase saturation flux densities. These modifications normally produce a lowering of the Curie temperatures to values too low for satisfactory use in many applications. Materials of the present invention provide high saturation flux densities with Curie temperatures higher than unmodified magnesium-manganese ferrites.

In general, it is known that the ferrites, which are cubic crystalline materials containing Fe_2O_3 and at least one other oxide, may be considered to be polycrystalline preparations of mixed crystals of the constituent compounds. The present invention, therefore, contemplates combining the constituents in proportions calculated to make chemically stoichiometric mixtures and controlling the conditions of the process to minimize loss of any metal oxide during the sintering operation. Although there have been references to lithium-nickel ferrites in the literature, notably

Wijn et al. in Philips Technical Review, August 1954, pages 49 to 58, the processes by which useful products are obtained are not taught therein.

An object of this invention is to provide lithium-nickel ferrite compositions and processing methods suitable for the production of ferromagnetic ceramic products with hysteresis loops of substantially square or rectangular shape.

Another object of this invention is to provide lithium-nickel ferrite compositions and processing methods suitable for the production of cores with short switching times.

Another object of this invention is to provide lithium-nickel ferrite compositions and processing methods suitable for the production of square loop products with high Curie temperatures.

A further object of this invention is to provide high saturation flux density lithium-nickel ferrites with high Curie temperatures.

These and other objects are obtained by utilizing a composition composed of compounds from the group including iron oxide, lithium oxide, nickel oxide, zinc oxide, and cadmium oxide and processing the composition as specified in this invention.

FIGURE 1 is a chart of composition ranges.

FIGURE 2 is a chart of composition ranges.

FIGURE 3 is a chart of composition ranges.

FIGURE 4 is a graph of squareness ratio plotted against percent nickel ferrite.

FIGURE 5 is a plot of a hysteresis loop.

FIGURE 6 is a graph of output voltages for a core being tested for use in coincident current memory application.

FIGURE 7 is a graph of calcination temperature plotted against squareness ratio.

The process of this invention is in its general aspects very similar to that currently employed for the production of ferromagnetic ceramics from compositions composed of the oxides of iron, magnesium and manganese. The first step is the intimate mixing of the proper proportions of the oxides involved, each in a fine state of subdivision. Instead of starting with the oxides themselves it is possible to start with a mixture materials in other than the oxide form, provided the starting materials will be changed to the specified oxide during processing. For example, it has been found that the use of the carbonates is convenient. The next step, if carbonates have been used, is calcining at approximately 600° C. to 850° C. for two to twenty hours. Calcining for a longer period, while unnecessary, does not appear to be harmful. The calcining step drives off the CO_2 from the carbonates and may result in some reaction. The fact that Li_2CO_3 melts at approximately 635° C. is of no concern because this compound is present in such a relatively small amount and its decomposition is effected during the reaction that takes place during calcining. Experimental results have shown that the magnetic properties of the final product can be improved by controlling the calcination temperature.

In general, for each compositional mixture there can be found a combination of calcining temperature and time which results in the greatest squareness.

Most of the data in this specification is taken from range surveys. Therefore, characteristics of specific compositions are subject to some improvement by adjusting processing parameters for the specific composition.

FIGURE 7 contains plots of the squareness ratio versus calcination temperature for mixtures lying at the 5% NiO point on line 1 of FIGURE 1. It will be seen that optimum squareness results over a 10° to 20° range of calcination temperature. In general, as the percent $NiO.Fe_2O_3$ increases, the optimum calcining temperature increases. The temperature is, however, kept below that required for sintering and full reaction. Calcining as described results in material soft enough that no grinding is required at this point, although a grinding operation may be employed if desired. The third step is the addition of a binder. The particular binder used is not critical. The trade preparation Flexalyn, for example, has proved quite satisfactory. The fourth step is pressing the resulting mixture into the desired form. The pressure of forming should be sufficient to form a closely coherent body. The pressures used should be simply those necessary to obtain this result. 30,000 pounds per square inch has proved to be quite satisfactory. The forms may be produced by extrusion processes if desired. Usually extrusion processes are less costly but make it more difficult to hold close tolerances. The fifth step is the sintering of the resulting forms. Satisfactory results have been obtained with sintering temperatures from 1150° C. to 1325° C. and sintering times from one to ten hours. Excessive coercivity results if sintering temperatures below that recommended are employed. In general, the highest sintering temperature permissible for satisfactory products increases with a decrease in the percentage of lithium in the composition. A slab containing compounds of lithium is used to support the forms being fired. It is desirable that the percentage of lithium in the slabs be at least equal to that in the forms. The use of slabs of the same composition as the ferrites being fired is a convenient expedient. The use of these slabs containing lithium appears to minimize the loss of lithium from the forms during the firing operation. It is in this step that this invention differs importantly from processes currently in use.

The forms are not quenched after firing, but rather held in the furnace at 1000° C. to 1125° C. for six to ten hours. This anneal appears to improve magnetic properties, and inadequate annealing may be corrected by a refiring at annealing temperatures. This refiring need not be in a neutral atmosphere but may be in the normal atmosphere of the furnace. In fact, refiring in a moving neutral atmosphere—the customary technique for refiring in a protective atmosphere—has proved harmful, probably because of increased loss of lithium.

The compositions involved in this embodiment of the invention may best be understood by reference to FIGURE 1. This figure represents all possible combinations within the ternary system:

$$Fe_2O_3:Li_2O:NiO$$

Line 1 connects the point indicating the composition $Li_{0.5}Fe_{2.5}O_4$ on the lithium oxide-iron oxide side of the triangle with a point indicating the composition $NiFe_2O_4$ on the nickel oxide-iron oxide side of the triangle. The most desirable lithium nickel ferrite compositions for applications requiring hysteresis loops of substantially square or rectangular shape have been found to lie on or near this line of stoichiometric mixtures.

FIGURE 4 shows a plot of the squareness ratio of samples lying on line 1. Table I tabulates magnetic properties of samples formed from a range survey of compositions on line 1.

TABLE I

Magnetic Properties of Lithium-Nickel Ferrites

Mol percent as mixed			R_s	B_m	H_m	H_c	B_s	H_{cs}	Sintering temp. ° C.
Li_2O	NiO	Fe_2O_3							
16.7	0	83.3	.50	1,080	2.5	1.5	2,960	2.3	1,200
15.8	2.5	81.6	.70	1,480	2.0	1.2	2,600	1.6	1,200
15.0	5.0	80.0	.81	1,600	2.3	1.5	3,000	2.0	1,250
13.3	10.0	76.7	.81	1,700	2.2	1.2	3,200	1.5	1,275
11.7	15.0	73.3	.72	1,340	1.8	1.1	2,750	1.5	1,275
10.0	20.0	70.0	.72	1,040	2.0	1.3	2,610	1.7	1,275
8.3	25.0	66.7	.41	770	2.3	1.4	2,780	2.0	1,275
6.7	30.0	63.3	.48	490	2.1	1.3	2,300	2.0	1,275
3.3	40.0	56.7	.57	600	1.9	1.3	2,300	1.8	1,275
0	50.0	50.0	.40	1,060	6.9	2.4	2,100	5.3	1,250

NOTE.—Where B_m is in gauss, H_m is in amp. turns, H_c is in oersteds, B_s is in gauss and H_{cs} is in oersteds.

Referring to FIGURE 5, the squareness ratio R_s is defined as

$$R_s=\frac{B_{-\frac{1}{2}H_m}}{B_{H_m}}$$

The denominator and enumerator of the latter represent respectively the magnetization for a field $+H_m$ and that for a field $-\frac{1}{2}H_m$. It will be clear that R_s is also a function of the maximum field H_m determining the size of the loop. When R_s is measured as a function of H_m, a value of H_m will be found for which R_s is at a maximum. In practice, an effort is normally made to use cores under conditions such that R_s is at or near the maximum value. If the hysteresis loop were perfectly rectangular, the squareness ratio would, of course, be 1. Practically achieved squareness ratios are always less than 1 with .80 being the figure most often used as the minimum acceptable for applications requiring substantially square or rectangular hysteresis loops. It will be noted that FIGURE 4 shows that squareness ratios as high as .83 have been obtained. The maximum squareness ratio shown in the aforementioned Wijn paper is .78. If .80 is taken as the minimum acceptable squareness ratio, satisfactory results with the particular processing conditions used to obtain the data for FIGURE 4 were obtained over that portion of the line included between 7 to 30 percent $NiO.Fe_2O_3$. If the cores are to be used in applications with less stringent squareness requirements so that squareness ratios of 0.6 and above may be tolerated, satisfactory results were obtained over that portion of the line included between 3 to 45 percent $NiO.Fe_2O_3$.

The hysteresis loop obtained with a sample from the 9% nickel ferrite point on line 1 of FIGURE 1 is shown in FIGURE 5. The squareness ratio of this particular sample is .81. The dynamic result obtained in a test of the suitability of this sample for use in a magnetic core memory is illustrated in FIGURE 6. Line 10 in FIGURE 6 is the maximum allowable output from a

half selected core; line 11 is the minimum allowable output from a fully selected core. For this particular memory, these limits are 30 and 80 millivolts respectively. The driving current for the test was 900 milliamperes with a 2 to 1 selection ratio. The smallest divisions along the horizontal or time axis are .2 of a microsecond. It will be seen that this core switches in approximately 1 microsecond. It will be noted that the output as a selected core is substantially greater than the accepted minimum for this particular memory and that the output as an unselected core is substantially less than the accepted maximum.

Table II contains a tabulation of squareness ratios for varying compositional mixtures including mixtures which are not stoichiometric and, therefore, do not lie on line 1 of FIGURE 1. These compositions and some of the Curie temperatures are plotted in FIGURE 2.

TABLE II

Magnetic Properties of Lithium-Nickel Ferrites (Non-Stoichiometric)

Mol percent as mixed			R_s	B_m	H_m	H_c	B_s	H_{cs}	Sintering temp. ° C.
Li_2O	NiO	Fe_2O_3							
17.7	0	82.3	.63	1,140	2.4	1.5	2,660	2.1	1,175
17.2	1.3	81.5	.63	1,300	2.5	1.6	2,900	2.1	1,175
16.8	2.5	80.7	.78	1,320	2.4	1.5	2,800	2.0	1,175
16.3	3.8	79.8	.78	1,300	2.4	1.6	2,720	2.1	1,175
15.9	5.1	79.0	.81	1,400	2.4	1.5	2,710	2.0	1,175
15.5	6.4	78.1	.77	1,210	2.4	1.5	2,790	2.0	1,175
15.0	7.7	77.3	.76	1,230	2.6	1.7	2,750	2.0	1,175
14.1	10.2	75.7	.75	1,030	4.2	2.6	2,680	3.6	1,175
13.3	12.7	74.0	.69	830	3.8	2.4	2,580	4.2	1,175
12.4	15.3	72.3	.48	750	2.7	1.6	2,660	2.6	1,175
10.6	20.4	69.0	.27	840	4.0	2.3	2,490	3.4	1,175
16.3	3.8	79.8	.63	1,000	2.0	1.2	2,980	1.9	1,250
15.9	5.1	79.0	.78	1,070	2.0	1.3	2,310	1.7	1,250
15.5	6.4	78.1	.74	1,450	2.0	1.3	3,080	1.8	1,250
15.0	7.7	77.3	.70	1,340	2.2	1.4	2,800	1.9	1,250
14.1	10.2	75.7	.68	1,290	2.7	1.7	2,800	2.2	1,250
16.3	3.8	79.8	.62	1,300	2.0	1.2	2,780	1.8	1,300
15.9	5.1	79.0	.68	1,260	1.8	1.2	2,690	1.6	1,300
15.5	6.4	78.1	.69	1,360	1.8	1.2	2,750	1.7	1,300
15.0	7.7	77.3	.63	1,230	1.9	1.2	2,830	1.7	1,300

NOTE.—Where B_m is in gauss, H_m is in amp.-turns, H_c is in oersteds, B_s is in gauss and H_{cs} is in oersteds.

The ternary system of FIGURE 2 is

$$Fe_2O_3:LiFeO_2:NiFe_2O_4$$

This system, which is actually a portion of that shown in FIGURE 1, has been chosen to expand the scale at which these results are plotted. It will be noted that lower squareness ratios and increased coercivity results from compositional variations in directions normal to the stoichiometric line. It is thought that excess Fe_2O_3 gives precipitated iron oxide and/or solid solution magnetite in the resulting material. It is thought that excess Li_2O gives a rock salt structure ($LiFeO_2$) instead of a spinal structure ($Li_{0.5}Fe_{2.5}O_4$). The degradation of characteristics occurs more rapidly for excesses of Fe_2O_3 than for excesses of Li_2O. The aforementioned use of slabs containing lithium to minimize the loss of lithium during the firing operations is important in that it minimizes unwanted compositional variations from the stoichiometric line with the resulting degradation of magnetic properties.

The values tabulated in Table II are from a range survey, and the magnetic properties of any specific composition may be improved by adjusting processing parameters. The previously noted variation of squareness ratio with calcination temperatures shown in FIGURE 7 is an example of the improvement possible by adjustment of processing parameters. If .80 is taken as the minimum acceptable squareness ratio, satisfactory results can be obtained with compositions lying approximately within area A in FIGURE 2. If the cores are to be used in applications with less stringent requirements so that squareness ratios of 0.6 and above may be tolerated, satisfactory results can be obtained with compositions lying approximately within area C on FIGURE 2. Commercial juke boxes often employ circuitry which can utilize cores with squareness ratios as low as 0.6.

If zinc ferrite in the proportions hereafter described is included as one of the components in the lithium nickel ferrite, the coercive force is substantially reduced. Lithium zinc ferrites are not rectangular hysteresis loop materials. However, by including zinc in the lithium nickel ferrite materials that possess rectangular hysteresis loops, relatively low coercivities and substantially higher flux densities can be obtained. Coercivity is reduced with increasing proportions of zinc ferrite in the composition, but to maintain squareness, the percentage of nickel ferrite must also be increased. Increasing the percentage of nickel ferrite tends to increase coercivity. The best compromises with respect to high squareness and low coercivity are normally obtained from compositions with approximately one to one mol percent ratios of zinc and nickel ferrites. The addition of zinc ferrite to the lithium nickel ferrite lowers the Curie temperature. However, the Curie temperature of the lithium nickel ferrite is relatively high so that even after an appreciable amount of zinc ferrite has been added, about 35 mol percent, the Curie temperature of the resulting composition is still around 400° C., considerably higher than that for magnesium manganese ferrites in current use. The processing considerations are the same whether or not zinc ferrite is a component, with the exception that longer annealing times, up to twenty-four hours, are desirable.

Compositions within the ternary system

$$Li_{0.5}Fe_{2.5}O_4:ZnFe_2O_4:NiFe_2O_4$$

are shown in FIGURE 3. Table III contains a tabulation of properties for several of these compositions.

TABLE III

Magnetic Properties of Lithium-Nickel-Zinc Ferrites

Ferrites, mole percent as mixed			R_s	B_m	H_m	H_c	B_s	H_{cs}	Sintering Temp. °C.
Li	Ni	Zn							
90	5	5	.45	1,580	1.63	0.99	3,690	1.63	1,250
85	10	5	.60	1,490	1.66	1.02	3,420	1.66	1,250
80	10	10	.69	1,990	1.66	1.05	3,650	1.66	1,250
75	15	10	.40	1,360	1.74	1.02	3,390	1.86	1,250
75	20	5	.73	1,660	2.05	1.23	3,130	2.09	1,250
70	15	15	.59	930	1.47	0.93	3,690	1.47	1,250
65	30	5	.65	1,450	2.31	1.49	3,260	2.39	1,200
65	20	15	.67	1,170	1.31	0.84	3,420	1.35	1,250
60	23	17	.72	1,340	1.21	0.78	3,570	1.28	1,200
60	20	20	.63	1,340	1.15	0.73	3,470	1.15	1,200
60	15	25	.39	930	1.18	0.70	3,230	1.14	1,200
55	40	5	.44	1,300	2.21	1.33	3,160	2,21	1,200
55	30	15	.76	1,660	1.34	0.86	3,600	1.32	1,200
55	25.7	19.3	.75	1,540	1.22	0.78	3,950	1.20	1,250
55	20	25	.50	1,390	1.22	0.73	3,390	1.17	1,250
50	28.5	21.5	.71	1,610	1.30	0.82	3,650	1.20	1,225
50	25	25	.67	1,890	1.20	0.77	3,560	1.10	1,225
50	20	30	.43	1,250	1.19	0.72	3,330	1.10	1,250
48	32	20	.46	1,440	1.02	0.60	3,650	0.89	1,175
45	20	35	.35	1,160	1.09	0.63	3,610	0.99	1,250
45	31.5	23.5	.65	1,440	1.20	0.74	3,910	1.20	1,225
45	35	20	.64	1,410	1.40	0.88	3,890	1.40	1,225
45	30	25	.69	1,890	1.20	0.77	3,560	1.10	1,225
42	28	30	.64	1,070	1.14	0.73	3,850	1.14	1,175
40	45	15	.65	1,550	1.10	0.65	3,630	0.97	1,225
40	40	20	.44	1,170	1.40	0.90	3,890	1.30	1,225
40	30	30	.68	1,520	1.10	0.70	3,790	1.10	1,225
40	25	35	.60	1,640	1.19	0.73	3,390	1.09	1,225
40	20	40	.31	910	0.91	0.53	3,470	0.84	1,200
35	37.5	27.5	.40	1,160	1.15	0.69	4,020	1.09	1,225
35	35	30	.38	1,350	1.02	0.59	3,890	0.90	1,225
35	30	25	.53	1,280	1.09	0.66	3,460	0.98	1,225
35	25	40	.35	1,050	0.90	0.53	3,340	0.83	1,200
30	40	30	.48	1,410	1.28	0.76	3,440	1.09	1,225
30	37	33	.41	1,050	1.07	0.62	3,700	0.65	1,250
30	35	35	.64	1,550	1.09	0.65	3,630	0.97	1,225
30	30	40	.38	1,010	0.91	0.53	3,080	0.86	1,200
20	50	30	.30	1,690	0.94	0.56	4,250	0.94	1,250
20	42	38	.32	970	0.95	0.66	3,580	0.68	1,200
100	0	0	.59	1,260	2.9	1.9	2,760	2.8	1,200
90	0	10	.44	1,080	1.5	.9	3,130	1.4	1,200
80	0	20	.24	1,180	1.5	.9	3,810	1.4	1,200
70	0	30	.13	1,570	1.4	.8	4,210	1.2	1,200
60	0	40	.16	1,440	1.1	.6	4,040	.9	1,200
50	0	50	.09	1,140	.9	.4	3,920	.7	1,200

NOTE.—Where B_m is in gauss, H_m is in amp.-turns, H_c is in oersteds, B_s is in gauss and H_{cs} is in oersteds.

The values tabulated above are from a range survey, and the magnetic properties of any specific composition may be improved by adjusting processing parameters.

If 0.80 is taken as the minimum acceptable squareness ratio, satisfactory results can be obtained with compositions lying approximately within area A in FIGURE 3. If the cores are to be used in applications with less stringent requirements so that squareness ratios of 0.6 and above may be tolerated, satisfactory results can be obtained with compositions lying approximately within area C on FIGURE 3. The change in squareness ratio with compositional variations is not as rapid in the system of FIGURE 3 as in the system of FIGURE 2. Therefore, area B has been outlined on FIGURE 3 to show the approximate area in which squareness ratios of 0.7 and above can be obtained. It may be noted that the region of highest squareness in the lithium nickel zinc ferrite when extrapolated to the stoichiometric line between lithium ferrite and nickel ferrite shown on FIGURE 1 coincides very well with the optimum region indicated on FIGURE 2 for lithium nickel ferrites which do not include zinc ferrite.

For applications which do not require rectangular hysteresis loops, the compositions lying within area D on FIGURE 3 provide high saturation flux densities with relatively high Curie temperatures. The area of high permeability extends, theoretically, to some point near 100% $ZnFe_2O_4$. However, increases in the zinc ferrite content progressively lower the ferromagnetic Curie temperature. Therefore, unless the ambient temperature is lowered as the Curie temperature is decreased, the permeability goes through a maximum as the amount of $ZnFe_2O_4$ is increased. By virtue of the high Curie temperature of the lithium-nickel ferrites, around 80 mol percent $ZnFe_2O_4$ can be tolerated if the products are to be used at normal ambient room temperatures. If elevated temperatures must be encountered, Curie temperatures plotted on FIGURE 3 show that with lesser percentages of zinc ferrite Curie temperatures of 400° C. and above may be obtained for high saturation flux density compositions. The high saturation flux density area includes the areas of squareness, so that high saturation flux density may be obtained with or without squareness as desired.

While exhaustive tests have not been made with cadmium ferrite as a component, research indicates that cadmium ferrite may be substituted on a one-for-one basis for zinc ferrite with substantially the same results.

There have thus been described improved ferrite materials exhibiting unexpected improvements in several of their useful magnetic properties. The proportions of the ingredients used should, in general, be within the percentage ranges given since use of other proportions results in products which either are not significantly improved or are inferior to previously known ferrites.

Ranges of time and temperature of heating for the calcining and sintering steps have also been given. The size of the body influences the sintering time necessary to bring about the desired properties. Very small bodies require shorter sintering times than large bodies. Also, for both steps, the required time of heating is usually in inverse ratio to the temperature used. There is usually an optimum value for heating temperature and other parameters for each composition.

Having thus described improved ferromagnetic prod-

ucts and processes for their manufacture, what is claimed is:

1. A process for manufacturing shaped lithium nickel ferrites having hysteresis loops of substantially rectangular shape comprising maintaining said shaped ferrites in direct contact with a slab containing lithium during the firing thereof, wherein the percentage of lithium in said slab is at least equal to the percentage of lithium in the lithium nickel ferrite.

2. A process for manufacturing shaped lithium nickel ferrites having hysteresis loops of a squareness greater than 0.6 and relatively low coercivity comprising maintaining said shaped ferrites in direct contact with a slab containing lithium during the firing thereof, wherein the percentage of lithium in said slab is at least equal to the percentage of lithium in the lithium nickel ferrite.

3. The process of claim 1 wherein the lithium nickel ferrite material consists essentially of $Li_{0.5}Fe_{2.5}O_4$, $ZnFe_2O_4$ and $NiFe_2O_4$ in the proportions of about 30 to about 98 mol percent $Li_{0.5}Fe_{2.5}O_4$ about 2 to about 70 mol percent $NiFe_2O_4$ and up to 40 mol percent $ZnFe_2O_4$.

4. The process of claim 1 wherein the lithium nickel ferrite material consists essentially of $Li_{0.5}Fe_{2.5}O_4$, $NiFe_2O_4$ and $CdFe_2O_4$ in the proportions of about 65 to about 95 mol percent $Li_{0.5}Fe_{2.5}O_4$, about 7 to about 35 mol percent $NiFe_2O_4$, and up to about 35 mol percent $CdFe_2O_4$.

5. The process of claim 2 wherein the lithium nickel ferrite material consists essentially of $Li_{0.5}Fe_{2.5}O_4$, $ZnFe_2O_4$ and $NiFe_2O_4$ in the proportions of about 30 to about 98 mol percent $Li_{0.5}Fe_{2.5}O_4$ about 2 to about 70 mol percent $NiFe_2O_4$ and up to 40 mol percent $ZnFe_2O_4$.

6. The process of claim 2 wherein the lithium nickel ferrite material consists essentially of $Li_{0.5}Fe_{2.5}O_4$, $NiFe_2O_4$ and $CdFe_2O_4$ in the proportions of about 65 to about 95 mol percent $Li_{0.5}Fe_{2.5}O_4$, about 7 to about 35 mol percent $NiFe_2O_4$ and up to about 35 mol percent $CdFe_2O_4$.

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