

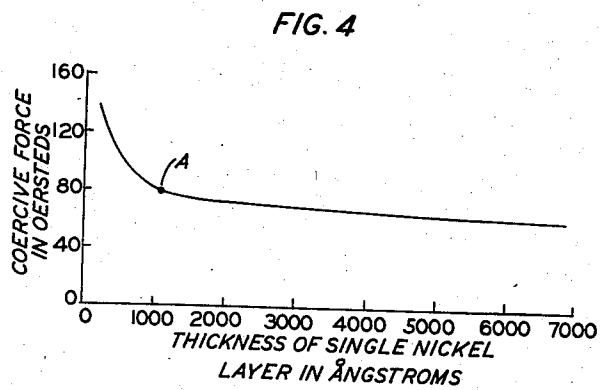
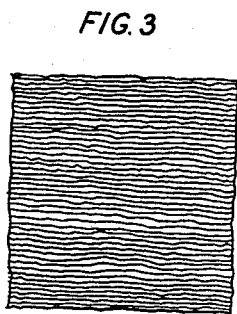
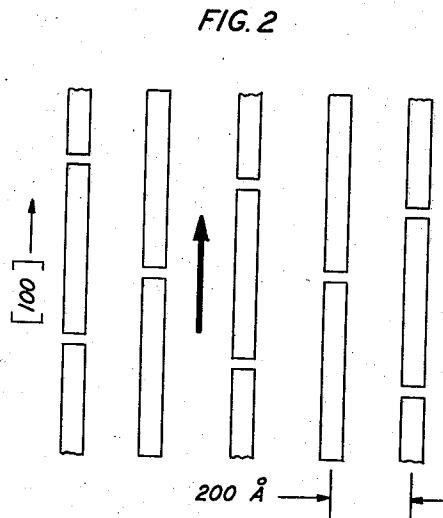
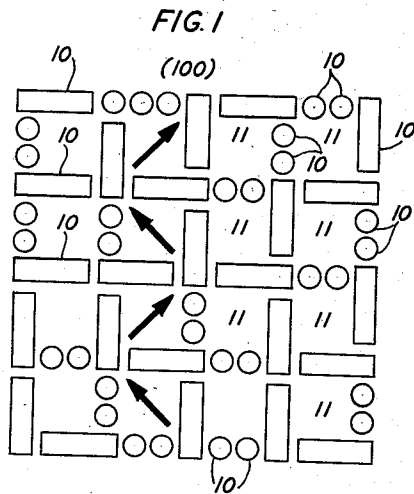
Jan. 12, 1960

R. M. BOZORTH ET AL

2,920,381

PERMANENT MAGNETS

Filed April 1, 1953



INVENTOR'S R. M. BOZORTH
E. A. NESBITT

BY

Hugh S. Wertz

ATTORNEY

2,920,381

PERMANENT MAGNETS

Richard M. Bozorth, Short Hills, and Ethan A. Nesbitt, Berkeley Heights, N.J., assignors to Bell Telephone Laboratories, Incorporated, New York, N.Y., a corporation of New York

Application April 1, 1953, Serial No. 346,152

3 Claims. (Cl. 29—183.5)

This invention relates to permanent magnets and more particularly to permanent magnets having a laminar structure.

An object of this invention is to provide a permanent magnet which can be formed from readily available materials.

Another object is to reduce the expense of manufacturing permanent magnets having intricate shapes.

A further object of this invention is to simplify the manufacture of high quality permanent magnets.

For many years it has been known that better permanent magnets can be made from alloys of magnetic materials than from the pure undivided magnetic material alone. Although the reasons for this superiority are not precisely known, it has been discovered that to obtain the best magnetic qualities from many of these alloys, it is necessary to heat treat them under exacting conditions of temperature and magnetic field. This process often causes the materials when cooled to be undesirably brittle for many uses or to have a hardness which makes it difficult to form them into intricate shapes. Moreover, some of the best magnetic alloys utilize materials that are frequently not readily obtainable. For these reasons, therefore, it is desirable to form permanent magnets from readily available materials, such as pure iron and copper, which can easily be made in intricate shapes and which are comparable in magnetic qualities with good alloy magnets. However, previous to the invention described herein, so far as is known, no simple and inexpensive process has been developed which produces permanent magnets having these desirable mechanical and magnetic properties.

The present invention is based on the discovery that a large number of very thin layers alternately of a magnetic and of a relatively non-magnetic material can be built up into a desired shape to form a permanent magnet possessing the above attributes. Because of the thinness of the layers the coercive force of the composite material is substantially higher than for the bulk magnetic material alone and by proper choice of magnetic material and layer thicknesses, the magnetic quality, that is, the quality $(BH)_{max}$, of the composite magnet can be made comparable to that of high quality alloy magnets. Specifically, a coercive force greater than 400 oersteds has been achieved in a composite iron-copper magnet having an iron layer thickness of roughly 200 Å. The magnetic saturation in this magnet is approximately inversely proportional to the copper layer thickness.

A more complete understanding of the nature and objects of this invention together with methods of practicing it, will best be gained by a study of the following detailed description given in connection with the accompanying drawings, in which:

Fig. 1 is an idealized schematic diagram showing domain orientation in an alloy permanent magnet formed without heat treatment in a magnetic field;

Fig. 2 is a diagram similar to that in Fig. 1 except that

it represents a case in which the magnet was formed with heat treatment in a magnetic field;

Fig. 3 shows a greatly magnified cross section of an embodiment of the present invention comprising a number of layers alternately of magnetic and of non-magnetic material formed, for example, by electrodeposition; and

Fig. 4 shows the experimental curve of coercive force versus magnetic layer thickness for a composite nickel-copper magnet.

Referring now in detail to the drawings, Fig. 1 shows, by way of example, the simplified magnetic and physical structure of the magnetic alloy Alnico 5 in the (100) plane. This material and its properties are described in an article entitled "Physical Structure and Magnetic Anisotropy of Alnico 5" by R. D. Heidenreich and E. A. Nesbitt in the Journal of Applied Physics, volume 23, pages 352 through 371, March 1952. When the alloy is not heat treated in a magnetic field, the precipitate rods grow in the three $\langle 100 \rangle$ directions as shown, the circles representing the rod ends. This results in the rod-surrounding matrix material 11 being cube-shaped with its domain magnetization, which is indicated by the arrows, lying in $\langle 011 \rangle$ directions in the (100) plane. Because of this domain arrangement, the residual induction of the matrix material is partially self-cancelling and this results in a residual induction substantially less than the saturation value. A similar self-cancellation of internal magnetization causes the low residual induction which is usually observed in sizeable samples of pure ferromagnetic metals, as, for example, iron. The present invention, in one of its more important aspects, is directed to the elimination of this undesirable effect.

Fig. 2 is an idealized representation of the magnetic and physical structure of the alloy represented by the diagram of Fig. 1 when this alloy is heat treated in a magnetic field. As a result of this treatment, all of the precipitate rods are substantially aligned in a single easy direction of magnetization parallel with the applied field at approximately 200 Å intervals while precipitation transverse to this direction is suppressed. This alignment causes a large increase in the residual induction of the alloy over that of the alloy as shown in Fig. 1. Moreover, because of the magnetic insulating effect of the precipitate rods, shape anisotropy becomes a factor in determining coercive force and under proper conditions may even become more important than crystal anisotropy.

Fig. 3 shows by way of illustration a greatly magnified cross section of a number of layers alternately of magnetic and of non-magnetic material formed upon each other in accordance with this invention by, for example, electrodeposition.

Although in determining the coercive force, the amount of the spacing between magnetic layers in this embodiment is less critical than the thickness of these layers, it should be understood that the separation of the magnetic material into layers is essential in order to obtain a high coercive force. The optimum thickness of the non-magnetic layers lies between roughly one-eighth to twice the thickness of the magnetic layers depending upon the residual induction required and the amount of shape anisotropy present. A ratio of one to one has been found satisfactory in a copper-iron combination designed for certain applications. The optimum thickness of the magnetic layers depends upon the particular material used but this thickness should be small enough to prevent the presence of domain boundaries between single magnetic domains.

In order to minimize self-cancellation of residual induction, such as is illustrated in Fig. 1 for Alnico 5 not heat treated in a field, it is desirable that alternate layers in the embodiment illustrated by Fig. 3 be of material

which is non-magnetic relative to the magnetic material. It is not necessary, however, that the non-magnetic layers be absolutely non-magnetic since it is possible to use materials of low magnetic saturation in conjunction with such elements as iron or cobalt.

Since such a variety of combinations of materials for the structure illustrated by Fig. 3 is possible and since each combination has characteristics not found in the others, it is not accurate to say that any one combination is best for every use. If high saturation is desired, materials such as copper and iron are satisfactory, while if high coercive force is sought, cobalt or a combination of manganese and bismuth may be used.

In forming the multiple layers of the embodiment illustrated in Fig. 3, various methods in addition to electrodeposition may be used. Mechanically forming the composite structure by rolling flat or stretching thin the layers is advantageous when other than pure metallic elements are used. If desired, thin sheets of alternate layers of materials may be rolled into tubes or cylinders which may then be stretched or drawn into fine diameter filaments or wires in order to obtain the desired layer thicknesses. This latter method is attractive because of the probability of increasing the effect of shape anisotropy on the coercive force. A series of fine parallel-spaced scratches on the magnetic layer surfaces in the direction of magnetization may serve additionally to increase the coercive force. After the layers have been reduced to the desired thickness by one of the above methods the unmagnetized structure may then be exposed to a strong magnetic field in order permanently to magnetize it.

Fig. 4 shows the experimentally determined values of coercive force in oersteds for a composite nickel-copper magnet for various thicknesses of the nickel layers. As the thickness of the nickel was made smaller than approximately 1000 A. there occurred a marked increase in the coercive force. At a layer thickness of 200 A. the coercive force was roughly twice its value for thicknesses above 1000 A. Point A on the curve is thought, in accordance with the explanation presented above, to represent approximately the minimum thickness for the formation of domain boundaries between magnetic domains in nickel. The location of this point, however, depends upon the magnetic material used. Tests with iron, for example, showed it to be located at about 800 A. thick-

ness while for manganese bismuthide it may occur at a thickness of the order of one micron. The minimum thickness of any layer ultimately depends upon the atomic diameter of the particular material in that layer. It is probable that iron cannot be formed in layers thinner than about 50 A.

While the foregoing discussion serves to illustrate the general principles of the present invention, this discussion is not intended to be in limitation of the invention. Various modifications of the structures illustrated or suggested, in addition to variations in the methods of forming these structures, will occur to those skilled in the art and may be made without departing from the spirit or scope of this invention.

What is claimed is:

1. A composite permanent magnet having a coercive force greater than 100 oersteds, said magnet including alternate layers of iron and of copper, each of said layers being from 150 A. to 250 A. in thickness.

2. A composite permanent magnet consisting of alternate layers of a ferromagnetic metal of the group consisting of nickel and iron and intermediate layers of copper, each of the layers being from 150 A. to 250 A. in thickness.

3. A composite permanent magnet having a coercive force greater than 100 oersteds, said magnet comprising alternate layers of nickel and of copper, each of said layers being between 150 A. and 250 A. in thickness.

References Cited in the file of this patent

UNITED STATES PATENTS

366,408	Lange	July 12, 1887
400,931	McCloud	Apr. 9, 1889
1,682,364	Ballantine et al.	Aug. 28, 1928
1,709,801	Muller	Apr. 16, 1929
1,974,079	Maier	Sept. 18, 1934
1,981,468	Roseby	Nov. 20, 1934
2,221,983	Mayer et al.	Nov. 19, 1940
2,619,454	Zapponi	Nov. 25, 1952
2,651,105	Neel	Sept. 8, 1953

OTHER REFERENCES

- Article "Permanent Magnets From Ultrafine Iron Powder," Kopelman; Electrical Engineering, May 1952, pp. 447-451.