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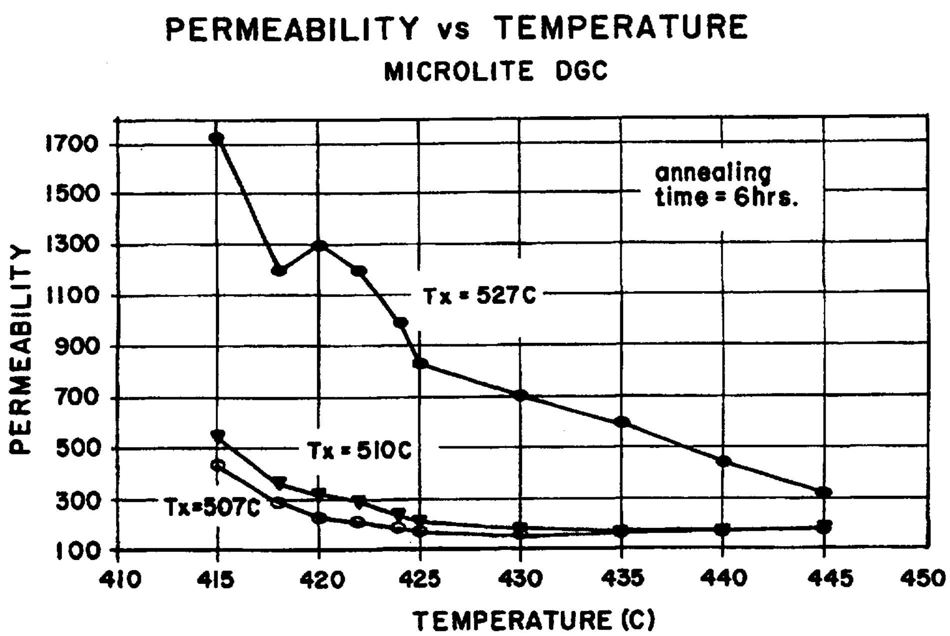

(57) Abstract

An electrical choke has a magnetic core with a distributed gap. The magnetic core is composed of an iron based, rapidly solidified metallic alloy. The distributed gap configuration is produced by an annealing treatment which causes partial crystallization of the amorphous alloy. As a result of the annealing treatment, the magnetic core exhibits permeability in the range of 100 to 400, low core loss (i.e. less than 70 W/Kg at 100 kHz and 0.1T) and excellent DC bias behavior (at least 40% of the initial permeability is maintained at a DC bias field of 3980 A/m or 50 Oe).

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DISTRIBUTED GAP ELECTRICAL CHOKE

BACKGROUND OF THE INVENTION

1. Field Of The Invention:

This invention relates to an amorphous metal magnetic core with a distributed gap for electrical choke applications; and more particularly to a method for annealing the amorphous core to create the distributed gap therein.

2. Description Of The Prior Art:

An electrical choke is an energy storage inductor. For a toroidal shaped inductor the stored energy is $W=1/2\ [(B^2 A_c l_m)/(2\mu_0\mu_r)]$ where B is the magnetic flux density, A_c is the effective magnetic area of the core, l_m is the mean magnetic path length, μ_0 is the permeability of the free space and μ_r is the relative permeability in the material.

By introducing a small air gap in the toroid, the magnetic flux in the air gap remains the same as in the ferromagnetic core material. However, since the permeability of the air ($\mu\sim1$) is significantly lower than in the typical ferromagnetic material (μ ~several thousands) the magnetic field strength(H) in the gap becomes much higher than in the rest of the core ($H=B/\mu$). The energy stored per unit volume in the magnetic field is $W=1/2(BH)$, indicating it is primarily concentrated in the air gap. In other words, the energy storage capacity of the core is enhanced by the introduction of the gap. The gap can be discrete or distributed. A distributed gap can be introduced by using ferromagnetic powder held together with nonmagnetic binder or by partially crystallizing an amorphous alloy. In the second case, ferromagnetic crystalline phases separate and are surrounded by nonmagnetic matrix. This partial crystallization mechanism is utilized in connection with the choke of the present invention.

Electrical chokes based on the principle of annealing Fe-base amorphous cores have been described in GB 2,117,979A and USP 4,812,181. In US patent 4,812,181 there is disclosed a method for achieving flat magnetization loop by subjecting Fe base amorphous cores to a long term (more than 10 hrs) anneal at temperatures higher than 410 ^{0}C. The method disclosed therein includes the step of crystallizing the surface of the amorphous ribbon, thereby applying stress on the amorphous bulk of the ribbon.

In GB 2,117,979A, an electrical choke is made based on heat treating Fe-base amorphous cores. The maximum permeability is reduced to between 1/50 and 1/30 of the original value, (for maximum permeability of 40,000 this treatment results in values ranging from about 800 and 1300) and the amorphous cores exhibit a degree of crystallization, which does not exceed 10% of the volume.

For applications in power supplies for notebook computers and other small devices there is a need for a very small size electrical choke with very low permeability (100-300), very low core losses, high saturation magnetization and which can sustain high DC bias magnetic fields.

SUMMARY OF THE INVENTION

The present invention provides electrical chokes having sizes ranging from about 8 mm to 45 mm OD with permeabilities in the range of 100 to 400 and low core losses (less than 70 W/kg at 100 kHz and 0.1T). Advantageously, the magnetic properties are maintained under DC bias (at least 40% of the initial permeability is maintained at a DC bias field of 3980 A/m or 50 Oe).

In addition, there is provided by the present invention a method for heat treating Fe base amorphous alloys in a controlled way to partially crystallize the bulk of the amorphous ribbon and generate microgaps in the cores. As a result of the distributed gaps, the aforementioned properties are achieved.

More specifically, there is provided in accordance with the invention a unique correlation between the degree of crystallization and the permeability values. In order to achieve permeability in the range of 100 to 400, bulk crystallization of the amorphous core is required, preferably of the order of 10 to 25% of the core volume.

In addition, the present invention requires certain annealing temperature and time parameters and degree of control of these parameters in order to achieve the desired choke properties.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be more fully understood and further advantages will become apparent when reference is had to the following detailed description and the accompanying drawings, in which:

Figure 1 is a graph depicting the relation between the permeability of the core and the annealing temperature, the different curves describing material with different crystallization temperatures;

Figure 2 is a graph depicting the relation between the permeability of the cores and the annealing temperature for different annealing times;

Figure 3 is a graph depicting the loading configuration of the cores for the annealing in order to achieve temperature uniformity within a few degrees;

Figure 4 is a graph depicting core loss in W/kg of the cores as a function of the DC bias field and the frequency;

Figure 5 is a graph depicting the permeability of the cores under DC bias field conditions;

Figure 6 depicts a typical cross-sectional Scanning Electron Microscopy (SEM) picture of the ribbon after the annealing; and

Figure 7 describes the permeability as a function of the volume percent of crystallinity.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 depicts the permeability of the annealed Fe-base magnetic core as a function of the annealing temperature. The permeability was measured with an induction bridge at 10 kHz frequency , 8-turn jig and 100 mV ac excitation. The annealing time was kept constant at 6 hrs. All the cores were annealed in an inert gas atmosphere. The different curves represent Fe-base alloys with small variations in the chemical composition and consequently small changes in their crystallization temperature. The crystallization temperatures were measured by Differential Scanning Calorimetry (DSC). A reduction in the permeability is observed with increasing annealing temperature for a constant annealing time. For a given annealing temperature the permeabilities scale according to the crystallization temperature, i.e. the permeability is highest for the alloy with the highest crystallization temperature.

Fig. 2 depicts the permeability of the annealed Fe-base cores with the same chemical composition as a function of the annealing temperature. The different curves represent different annealing times. The plot indicates that for temperatures higher than 450 ^{0}C the effect of the annealing temperature dominates the effect of the annealing time.

The appropriate annealing temperature and time combination are selected for an Fe-B-Si base amorphous alloy on the basis of the information in Figs. 1 and 2. This selection can be made provided the crystallization temperature (T_x) and/ or chemical composition of the alloy is known. For example, for $Fe_{80}B_{11}Si_9$ which has T_x=507 ^{0}C in order to achieve permeabilities in the range of 100 to 400 annealing temperatures in the range of 420 to 425 ^{0}C for 6 hrs are appropriate.

Referring again to Fig. 1, reproducibility and uniformity for a given permeability value are obtained when a temperature variation of less than one or two degrees is maintained. Special loading configurations have been developed for the annealing process so that the uniformity and reproducibility of the temperature in the oven are established. For a box type inert gas oven wire mesh Al plates(2) are stacked according to Fig. 3 and the arrangement is placed in the center of the oven. The Al plates are the substrates that hold the cores(1) during the anneal.

Typical magnetic characterization data for the chokes, such as core loss and DC bias are shown in Figs. 4 and 5. The core loss data are plotted as a function of the DC bias field and the different curves represent different measuring frequencies. The data shown are for cores with 25 mm OD. An important parameter for the choke performance is the percent of the initial permeability that remains when the core is driven by a DC bias field. Fig. 5 depicts a typical DC bias curve for a core having 35mm OD.

Cross-sectional scanning electron microscopy (SEM) and x-ray diffraction (XRD) were performed to determine the distribution and percent crystallization of the annealed cores. Fig. 6 depicts a typical cross-sectional SEM indicating that both the bulk of the alloy and the surface are crystallized. This is readily distinguished from the method described in US patent 4,812,181, in which only the surface is crystallized.

The volume percent of the crystallization was determined from both the SEM and XRD data and is plotted in Fig. 7 as a function of permeability. For permeabilities in the range of 100 to 400 bulk crystallization in the range of 5 to 30% is required.

Having thus described the invention in rather full detail, it will be understood that such detail need not be strictly adhered to but that further changes and modifications may suggest themselves to one skilled in the art, all falling within the scope of the invention as defined by the subjoined claims.

What is claimed is:

1. An electrical choke, comprising a magnetic core having a distributed gap, said magnetic core consisting essentially of an Fe -base amorphous metal alloy that is partially crystallized.

2. An electrical choke as recited by claim 1, having a permeability ranging from about 100 to 400 at 10 kHz, 40% of the initial permeability being maintained at DC bias magnetic field of 3980 A/m (50 Oe), a core loss less than 70 W/kg at 100 kHz and 0.1T bias magnetic field, and a high saturation flux density.

3. A method for producing an electrical choke having a core composed of an amorphous metal alloy, comprising the step of: annealing the choke in a protective atmosphere at temperature and time parameters that depend upon the crystallization temperature and chemical composition of the amorphous metal alloy, said time and temperature parameters being selected for a specific iron-based alloy in accordance with data from Figures 1 and 2.

4. A method for producing an electrical choke, as recited by claim 3, wherein said amorphous metal alloy is $Fe_{80}B_{11}Si_9$, said annealing temperature is 425 ^{0}C and said annealing time is about 6-8 hrs.

5. A method for producing an electrical choke, as recited by claim 3, wherein said amorphous metal alloy is $Fe_{80}B_{12}Si_8$, said annealing temperature is 455 ^{0}C and said annealing time is about 4 hrs.

6. A method for producing an electrical choke, as recited by claim 3, wherein said annealing step is carried out in the absence of a magnetic field.

7. A method for producing an electrical choke, as recited by claim 3, wherein said temperature is controlled to within about 2-5 degrees Centigrade during said annealing step, whereby said choke, after said anneal exhibits substantially constant permeability.

8. A method as recited in claim 7, wherein said annealing step is carried out in a box type convection oven and said cores are arranged within said oven in the manner depicted by Figure 3 to thereby control said temperature within about 2 to 5 degrees Centigrade.

9. An electrical choke produced in accordance with the method recited in claim 3, said choke, upon being annealed, being partially crystallized so that substantially all of the amorphous metal therein is about 10 to 25% crystalline.

10. An electrical choke produced in accordance with the method recited in claim 3, wherein said partial crystallization causes formation of αFe and Fe_2B crystal therein.

11. An electrical choke as recited by claim 6, in which said core is coated with a thin high temperature resin which electrically insulates said core and maintains core integrity.

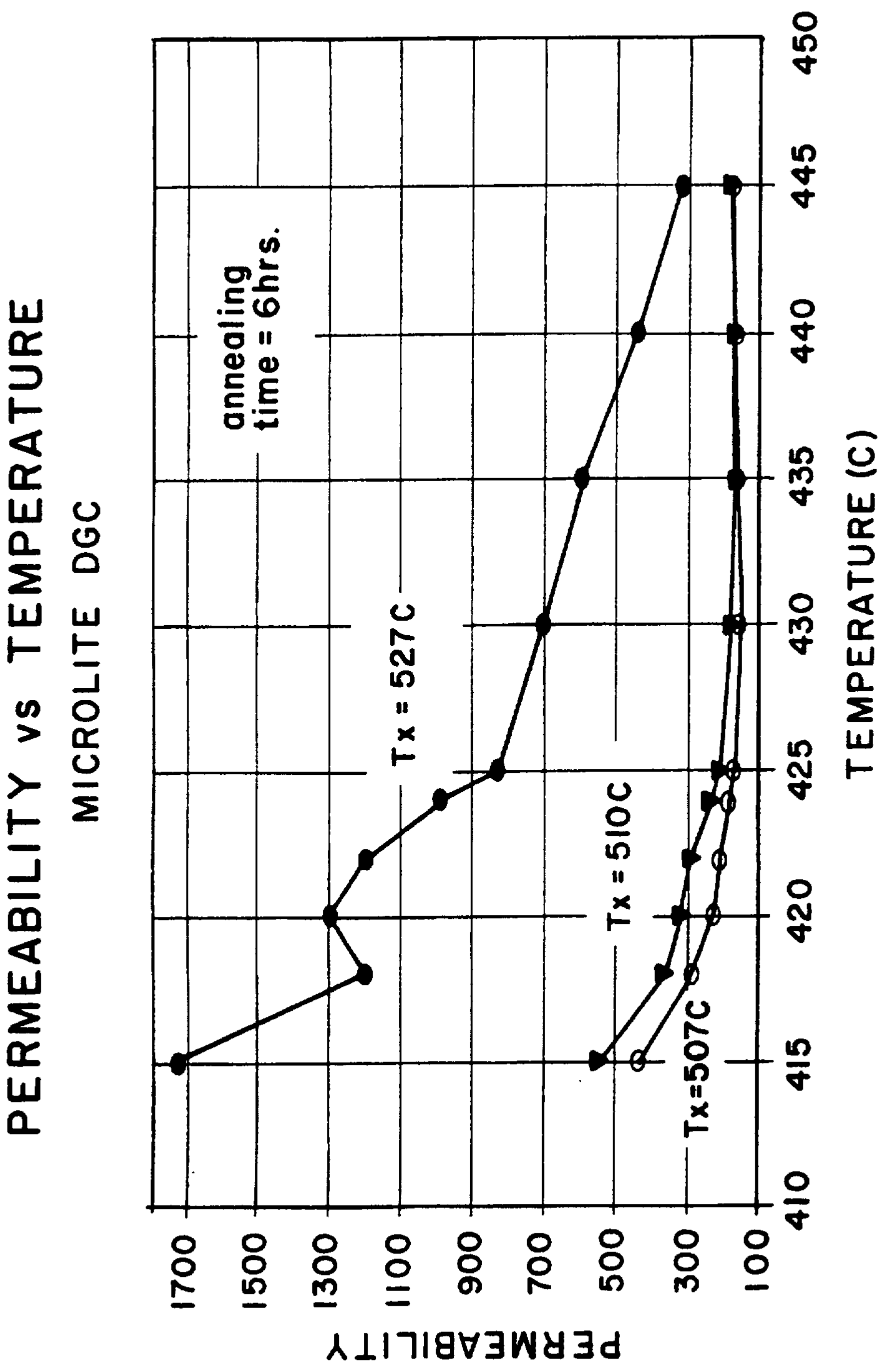
PERMEABILITY vs TEMPERATURE
MICROLITE DGC
annealing
time = 6hrs.
Tx = 527C
Tx = 510C
Tx=507C
PERMEABILITY
1700
1500
1300
1100
900
700
500
300
100
410
415
420
425
430
435
440
445
450
TEMPERATURE (C)

FIG. 1

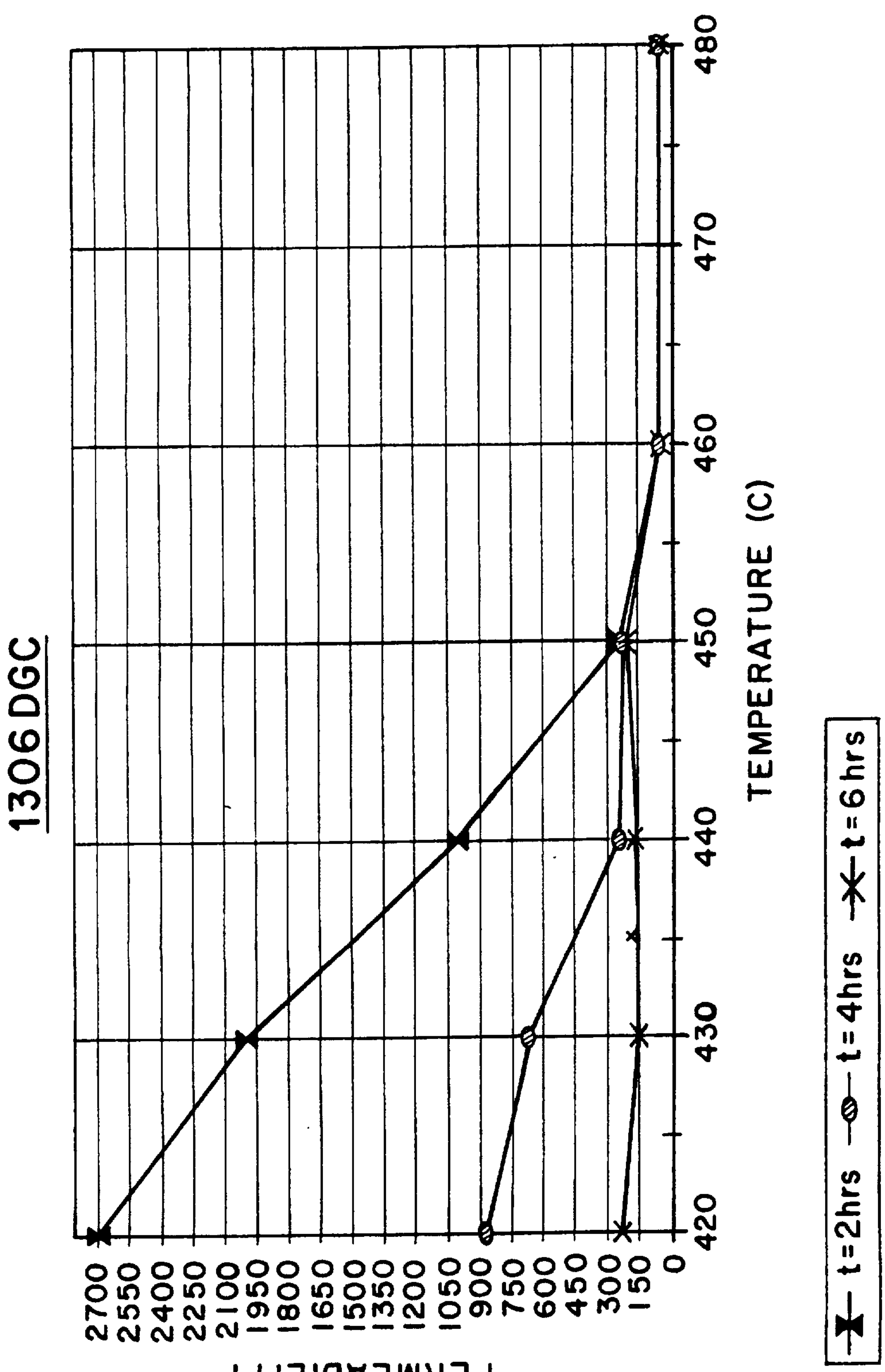
1306DGC
PERMEABILITY
2700
2550
2400
2250
2100
1950
1800
1650
1500
1350
1200
1050
900
750
600
450
300
150
0
420
430
440
450
460
470
480
TEMPERATURE (C)
t=2hrs
t=4hrs
t=6hrs

FIG. 2

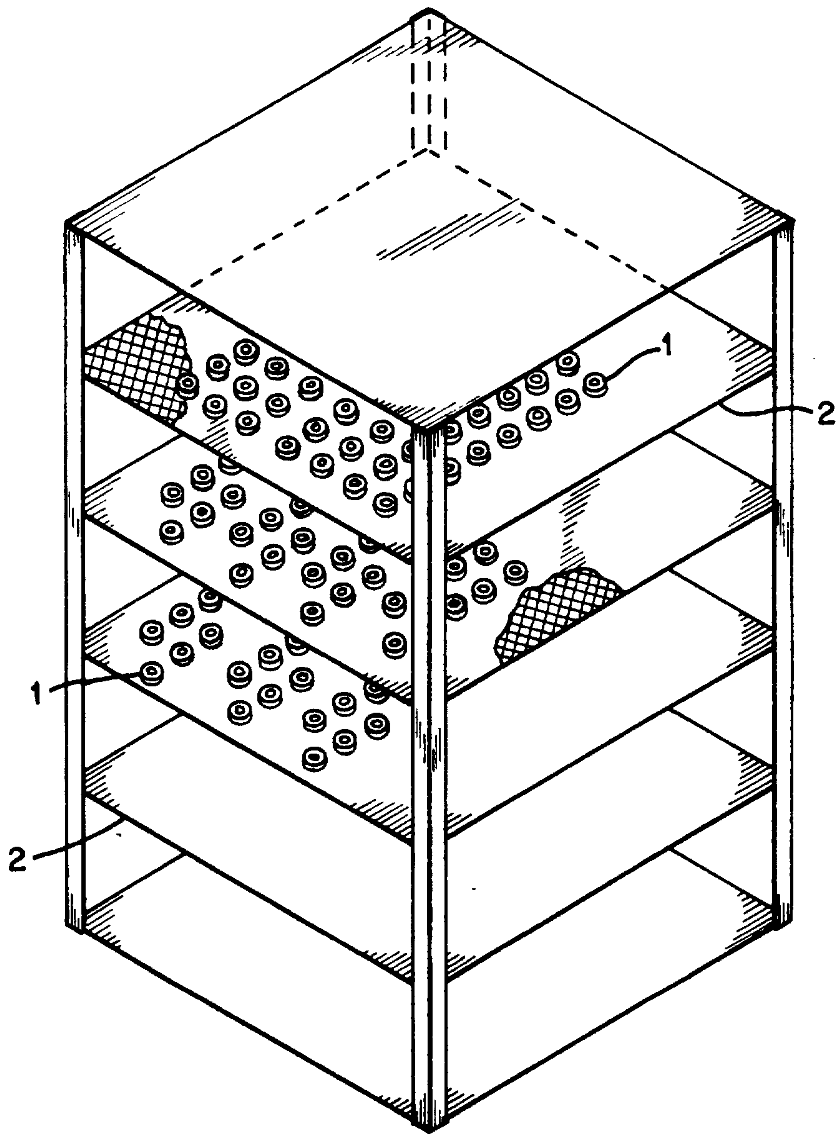

FIG. 3

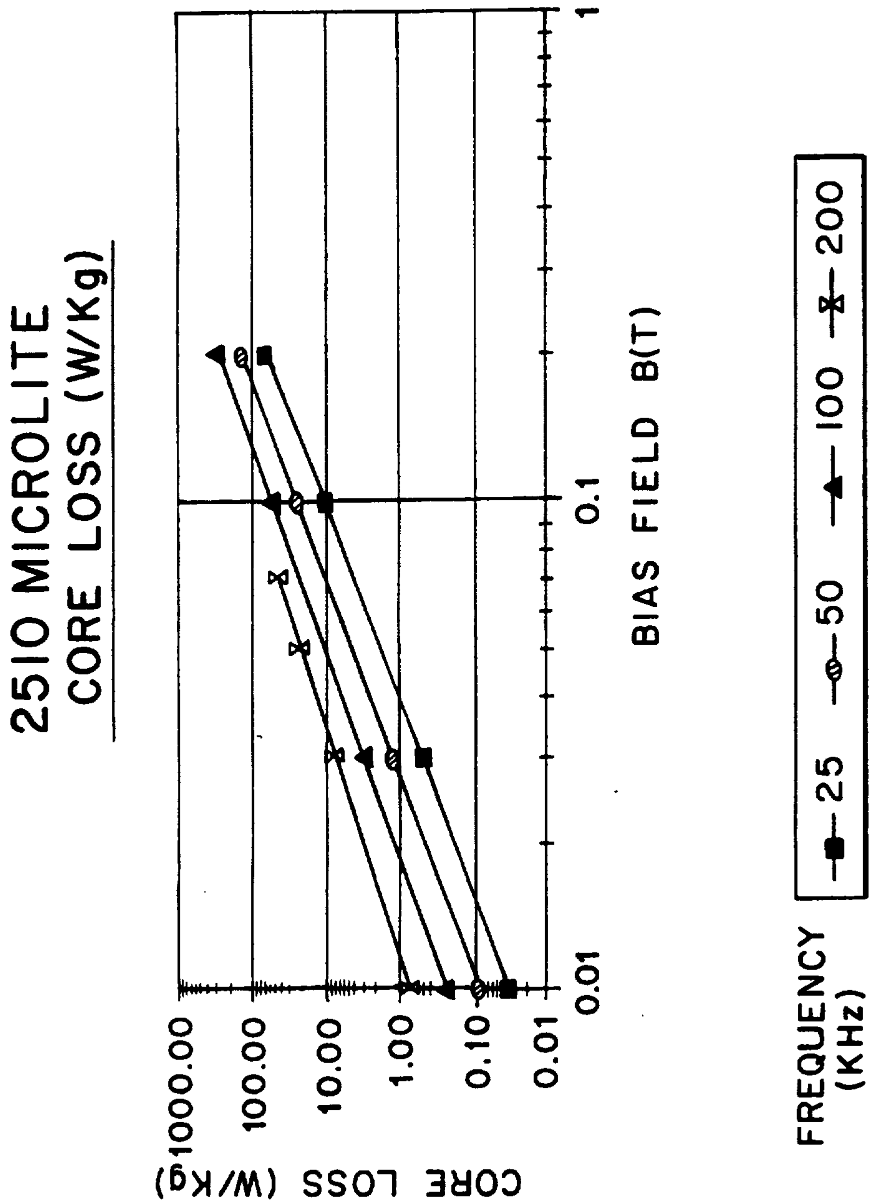
2510 MICROLITE
CORE LOSS (W/Kg)
CORE LOSS (W/Kg)
1000.00
100.00
10.00
1.00
0.10
0.01
0.01
0.1
1
BIAS FIELD B(T)
FREQUENCY (KHz)
25
50
100
200

FIG. 4

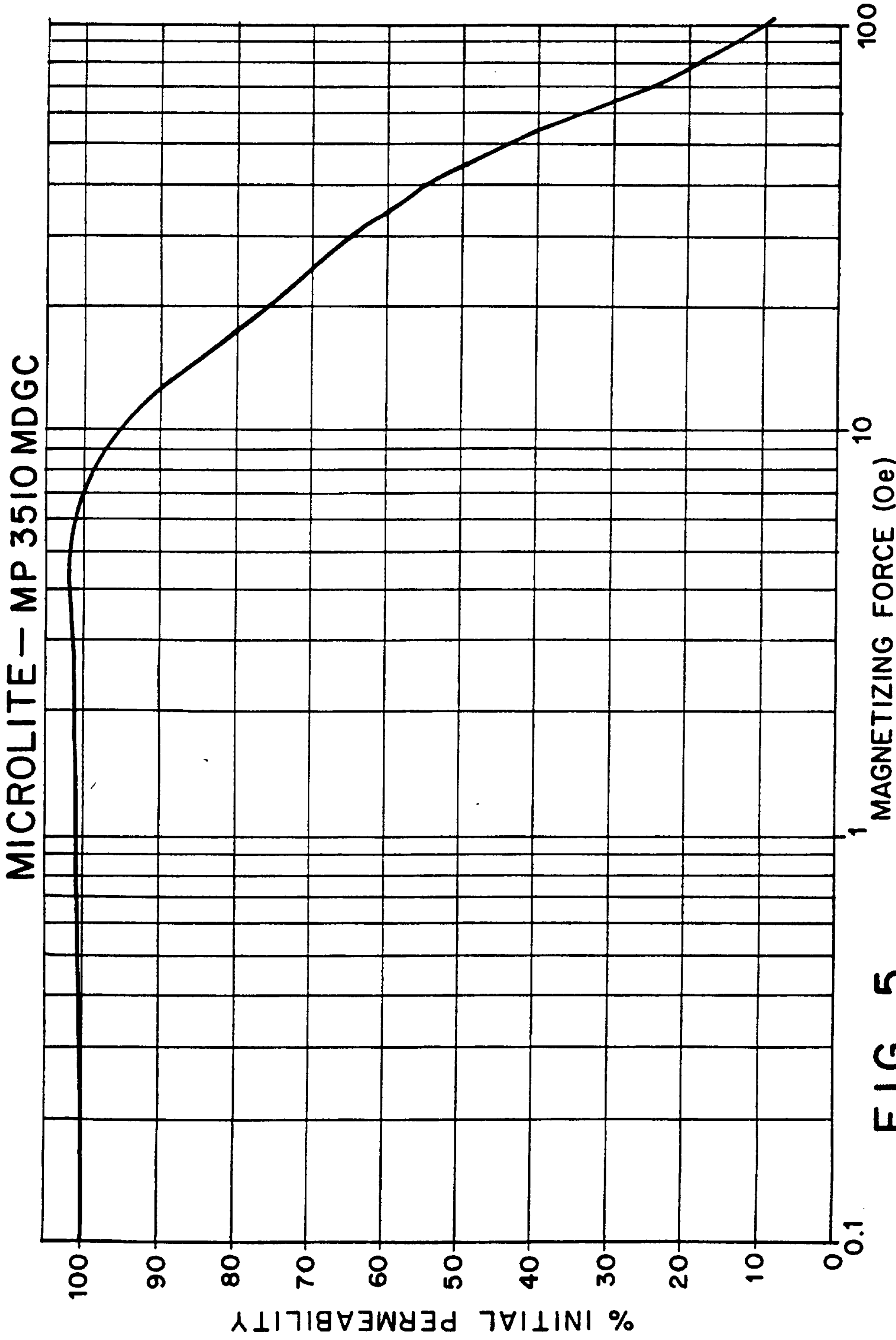
MICROLITE — MP 3510 MDGC
MAGNETIZING FORCE (Oe)
0.1
1
10
100
% INITIAL PERMEABILITY
100
90
80
70
60
50
40
30
20
10
0

FIG. 5

SA1 #15 (STD)

$\mu = 274$

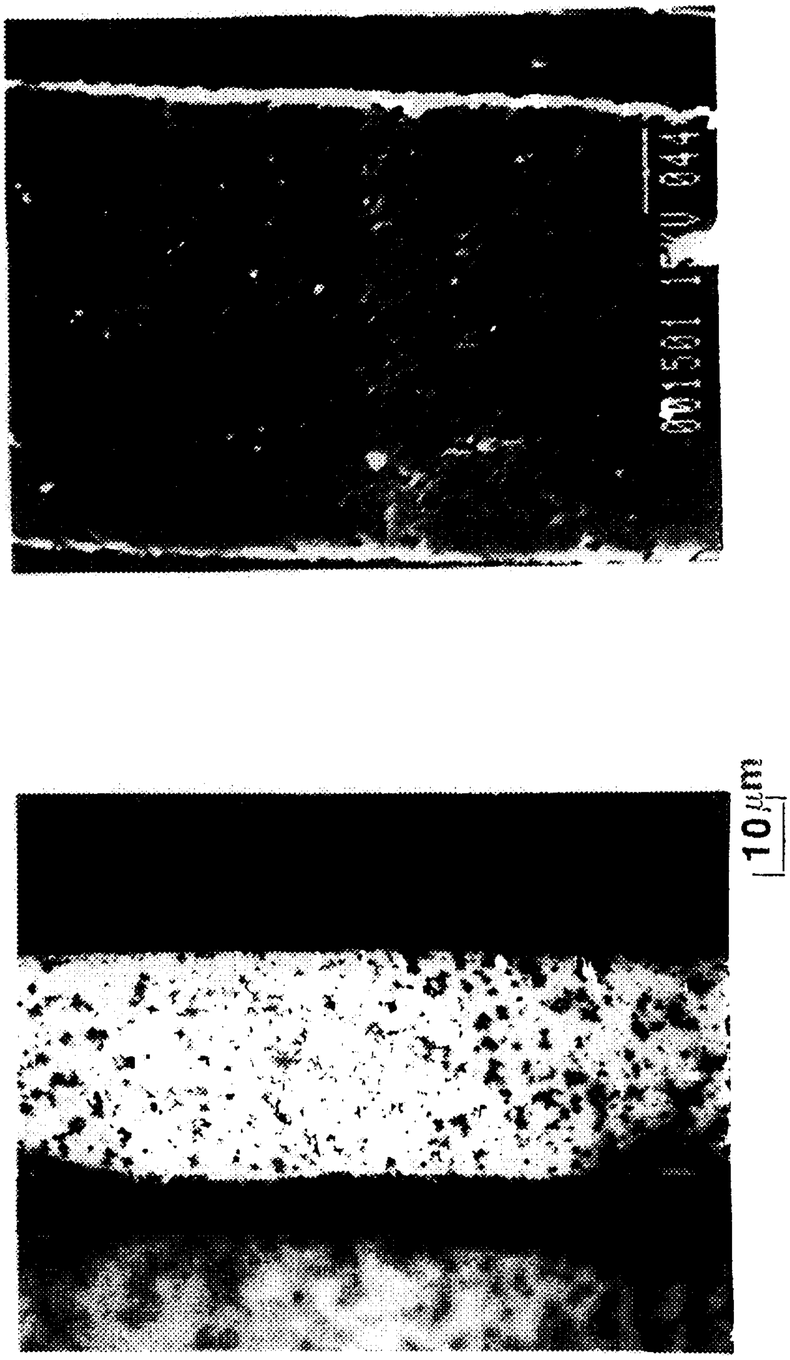

Fig. 6

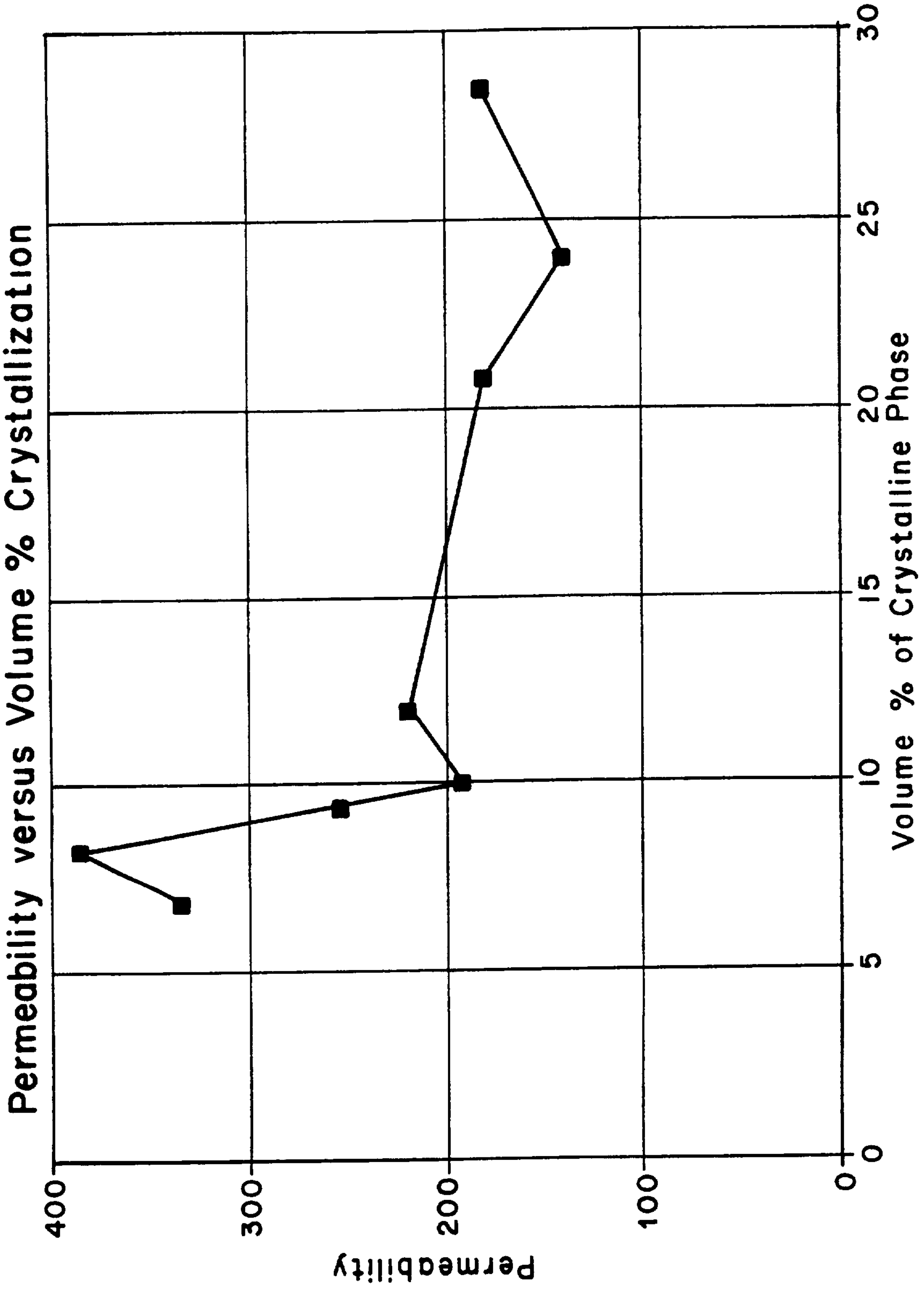
Permeability versus Volume % Crystallization
Permeability
400
300
200
100
0
Volume % of Crystalline Phase
0
5
10
15
20
25
30

FIG. 7

INTERNATIONAL SEARCH REPORT

Interr • pplication No
PCT/US 97/00178

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01F17/06 H01F27/25 H01F27/34 H01F1/153

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 117 979 A (TELCON METALS LTD) 19 October 1983 cited in the application see page 1, line 21 - line 41; example 1 ---	1,3,7
X	IEEE TRANSACTIONS ON MAGNETICS, vol. 20, no. 5, September 1984, NEW YORK US, pages 1415-1416, XP002030239 R.V.MAJOR ET AL : "Development of amorphous Fe-B based alloys for Choke and Inductor Applications"	1,3,6,7
A	see the whole document ---	2,4,5
X	EP 0 513 385 A (MITSUI PETROCHEMICAL IND) 19 November 1992 see page 2, line 8 - page 8, line 15; claims 1-3; figure 10 --- -/--	1,3,9,10

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
25 April 1997	14.05.97

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INTERNATIONAL SEARCH REPORT

Inter : .pplication No
PCT/US 97/00178

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 300 950 A (LUBORSKY FRED E ET AL) 17 November 1981 see claims 1,2; example 8 ---	1,5
A	JOURNAL OF MAGNETISM AND MAGNETIC MATERIALS, vol. 115, no. 2 / 03, 11 September 1992, pages 245-249, XP000329941 SINGHAL R ET AL: "CRYSTALLIZATION OF GLASSY FE80B20-XSIX(0 X 12) ALLOYS" -----	

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Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inter Application No
PCT/US 97/00178

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		DE 69124691 D	27-03-97
		WO 9209714 A	11-06-92
		JP 5005164 A	14-01-93
		KR 9514314 B	24-11-95
US 4300950 A	17-11-81	US 4217135 A	12-08-80
		BR 7902477 A	20-11-79
		DE 2915737 A	08-11-79
		FR 2423547 A	16-11-79
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