



(51) International Patent Classification:
H01L 39/02 (2006.01)

(21) International Application Number:
PCT/GB2011/052448

(22) International Filing Date:
9 December 2011 (09.12.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1102153.2 8 February 2011 (08.02.2011) GB

(71) Applicant (for all designated States except US):
SIEMENS PLC [GB/GB]; Faraday House, Sir William
Siemens Square, Frimley, Camberley, Surrey GU16 8QD
(GB).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **CALVERT, Simon**
[GB/GB]; 17 Akeman Street, Combe, Witney, Oxfordshire
OX29 8NZ (GB).

(74) Agents: **FRENCH, Clive Harry** et al.; Siemens Ak-
tiengesellschaft, Postfach 22 16 34, 80506 Munich (DE).

(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO,
DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR,
KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME,
MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD,
SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR,
TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

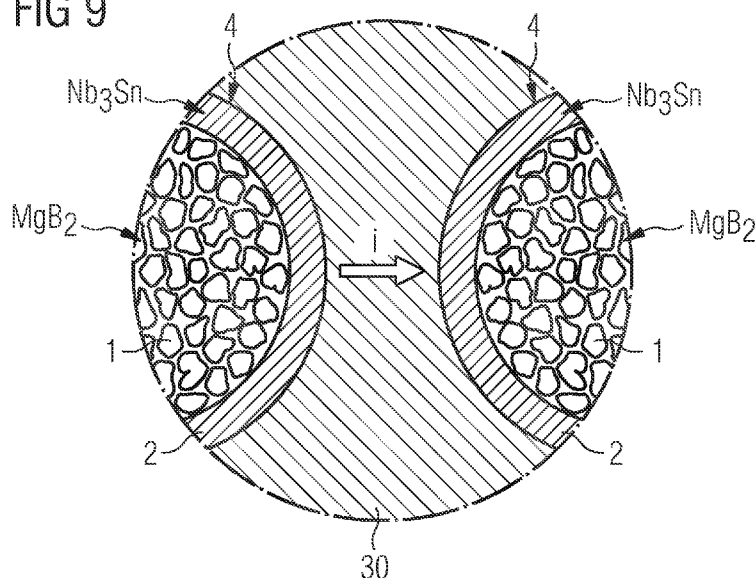
(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU,
TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,
DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU,
LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,
GW, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: JOINTS WITH VERY LOW RESISTANCE BETWEEN SUPERCONDUCTING WIRES AND METHODS FOR MAK-
ING SUCH JOINTS

FIG 9



(57) Abstract: Joints between first and second
superconducting wires (7), each comprising a
number of filaments (4) which each comprise a
superconductive core (1) within a respective
sheath (2), wherein the sheaths (2) comprise
niobium (Nb) and the filaments (4) are embed-
ded within a matrix (3) are disclosed. The joint
itself comprises a certain length (20) of fila-
ments exposed by removal of the matrix (3);
over the certain length, the sheaths (2) are of
niobium-tin (Nb₃Sn); and a superconductive
path is provided between superconductive
cores (1) of filaments (4) of the first wire (7),
through the Nb₃Sn sheaths (2) of the filaments
(4) to the cores (1) of the second wire (7).
Methods for making such joints are also
provided.

JOINTS WITH VERY LOW RESISTANCE BETWEEN SUPERCONDUCTING WIRES AND METHODS FOR MAKING SUCH JOINTS

The present application relates to methods for joining superconducting wires
5 together, and joints as may be made by such methods.

When manufacturing equipment such as electromagnets from superconducting wire,
it is commonly required to join separate lengths of wire together. In order to maintain
the superconductivity of the equipment, the joints must also be superconducting, or
10 at least exhibit very low resistance, if operation in 'persistent-mode' is required.
Typically, joint resistances of $\sim 10^{-13}$ ohms are required to enable this mode of
operation. Operation in 'persistent mode' is highly desirable as this enables the
power supply to be dispensed with after initial energisation has been achieved.

15 Recent developments in superconducting materials have led to the use of
magnesium diboride MgB_2 as a superconducting material. Magnesium diboride
 MgB_2 has the benefit of exhibiting superconductivity at higher temperatures than
more conventional materials, avoiding the need to cool the superconductor to very
low temperatures. However, the material itself is brittle, and difficult to join to form
20 persistent joints.

Fig. 1 shows a cut-away view of a typical MgB_2 -core superconducting conductor 10.
Superconducting filaments 4 comprise an MgB_2 core 1 in an essentially granular,
powder, form, held within sheaths 2 of niobium metal. These MgB_2 -filled niobium
25 sheaths are further encased in a matrix 3 of high strength, conductive metal or alloy,
such as the Cu-Ni alloy known as "MONEL". The matrix 3 and filaments 4 make up
superconducting wire 7. The purpose of the niobium 2 is to prevent unwanted
reactions occurring between the MgB_2 and matrix material during wire manufacture.

30 In one manufacturing method, known as the ex-situ process, granulated or powdered
 MgB_2 is placed in a number of niobium lined holes drilled into a billet of matrix
material. The complete billet is then drawn to the required final wire diameter. The
Niobium-cased superconducting filaments are formed and compacted during the
drawing process.

35

The matrix 3 provides an electrically conductive shunt, and thermal sink. Should any
of the superconducting filaments 4 quench, then heat will be carried away from the

quenched region by the matrix 3, and electric current will flow through the lower resistance offered by the matrix. This will allow the quenched part of the filament to cool back to superconducting condition. The matrix also makes the superconducting wire more mechanically robust.

5

The conductor 10 typically also comprises a stabilising channel 5. This may be of copper or another material, or combination of materials. The channels should be electrically and thermally conductive. In the illustrated example, the wire 7 is soldered 6 into a cavity of the channel 5. The channel 5 adds further electrical and thermal stability, and mechanical robustness, to the superconducting wire 7, in the same manner as explained with reference to matrix 3.

In order to make a superconducting joint, two conventional approaches have been adopted: firstly, a joint may be formed directly between the MgB_2 cores 1 of the wires 15 to be joined. Alternatively, another material, which is also superconducting at the temperature of operation of the wire, is used to electrically join the MgB_2 cores 1 of the wires together in a superconducting arrangement. Typically, known joining methods involve exposing the MgB_2 cores of the superconducting wires to be joined, and mechanically pressing the exposed MgB_2 particles of the respective wires 20 together to form the superconducting joint. In some known arrangements, an intermediate layer of a superconducting material, typically a metal such as indium is interposed between the exposed cores of the respective wires, to increase the contact surface area and improve mechanical adhesion between the particles of the respective wires. Such methods require significant mechanical loads to be applied to 25 the MgB_2 particles. The MgB_2 particles are relatively brittle, and applying such significant mechanical loads risks fracturing the MgB_2 superconducting material, leading to failures of the superconducting joint.

In some known methods, MgB_2 particles are exposed and heated, for example when 30 joined by MgB_2 powder or a reaction between magnesium and boron powders. If the MgB_2 particles are exposed, there is a risk of oxidation. Failures may occur some time after the jointing process, after the joint is built in to a superconducting device, such as a magnet within a cryogen vessel. Such failures are very expensive and time-consuming to repair, due to the access problems of reaching a joint within a 35 superconducting device built into a cryogen vessel, and/or vacuum vessel, and so on. It is therefore an object of the invention to provide methods for joining MgB_2 -

cored superconducting wires which reduce the risk of mechanical damage, or oxidation, to the MgB_2 particles.

However, tests on conventional joints between MgB_2 -based superconducting wires have shown magnetic field tolerance values poorer than expected. This is believed to be due to conduction actually taking place through the niobium of the sheaths rather than through the superconducting joints between MgB_2 particles of the respective wires. Niobium is a "Type II" superconductor, but has a very low upper critical magnetic field strength B_{c2} when compared to other Type II superconductors such as the alloy niobium titanium. The critical field of niobium is in the range of a few tenths of a tesla with exact value depending on many factors, most notably the current density. Since it is highly desirable that joints for use in superconducting magnets should be able to tolerate quite high magnetic fields, any jointing method that utilises the niobium sheaths for current transport is likely to be of little use.

15

Certain conventional methods for producing superconducting joints are described in WO2007/128635A1, US2008/0236869A1, US6921865B2 and US7152302B2.

The present invention accordingly provides methods for producing superconducting joints between niobium-sheathed superconducting wires, such as those with a MgB_2 -core, or those with a NbTi core, and joints such as may be produced by the methods of the present invention, as defined in the appended claims.

The above, and further, objects, characteristics and advantages of the present invention will become more apparent from the following description of certain embodiments of the present invention, in conjunction with the accompanying drawings, wherein:

Fig. 1 shows a cut-away view of a typical niobium-sheathed, MgB_2 -cored superconducting conductor;

Fig. 2 shows two superconducting wires at an early stage in a joining method of the present invention;

Fig. 3 shows the wires of Fig. 2 undergoing a later step in the joining method of the present invention;

35 Figs. 4A-4C show cross sections of a niobium-sheathed, MgB_2 -cored superconducting filament at various stages in a joining method of the present invention;

Fig. 5 shows an enlarged partial view of Fig. 4C;

Fig. 6 shows the wires of Figs. 2 and 3 at a later stage in the method of the present invention;

Fig. 7 shows a completed joint according to an embodiment of the present invention,
5 following the step illustrated in Fig. 6;

Fig. 8 shows a partial cross-section through a joint according to the present invention, such as that illustrated in Fig. 7;

Fig. 9 shows an enlargement of the area identified as IX in Fig. 8;

Fig. 10 shows a wire prepared for joining according to another embodiment of the
10 present invention;

Fig. 11 illustrates various stages in a method of forming a superconducting joint according to an embodiment of the present invention; and

Fig. 12 shows a cross-section of a joint according to the present invention as may be formed by the method illustrated in Fig. 11.

15

The present invention provides methods for joining niobium-sheathed superconducting wires and joints such as may be prepared by such methods.

According to the present invention, the niobium-sheathed superconducting filaments
20 4 are immersed in liquid tin (Sn), so that the niobium sheath reacts with the tin to form Nb_3Sn . Conventionally, Nb_3Sn superconductor filaments have been prepared by diffusion of tin into filaments of niobium during a long, high temperature, reaction process. A similar process is employed for jointing niobium-sheathed wires according to the present invention.

25

The Nb_3Sn is a superconductor having a much higher field tolerance ($\sim 18\text{T}$ at 4K) than niobium ($\sim 0.5\text{T}$ at 4K), and a high critical temperature T_c of about 18K . Nb_3Sn also has a large coherence length, which enables lossless current transfer between
30 the reacted sheath and the MgB_2 superconductor granules or powder. The coherence length indicates the size of gap which may exist between superconductors, yet superconductivity to still exist between them. By having a sheath material such as Nb_3Sn with a large coherence length, superconductivity may be maintained between the sheath material and enclosed grains of MgB_2 . Thus, if the
35 niobium sheath in superconducting wires can be converted to Nb_3Sn , the field tolerance of the joint should increase substantially and the transport current between the grains of MgB_2 and the sheath material should be improved.

In known methods of joining MgB_2 cored wires, it is believed that the majority of electric current passes through the sheath material, rather than directly from the core of one wire to the core of the other. The present invention provides a particularly
5 advantageous sheath material to enable such current transfer to operate more effectively.

The reacted sheaths 2 of filaments 4 are joined by superconducting materials. The present invention avoids the need to expose MgB_2 grains and to make mechanical
10 joins between them. It is believed that exposure of MgB_2 to hot tin will result in the formation of undesired compounds as contaminants. This will degrade the attainable quality of the junction.

Joints according to the invention have a relatively high field tolerance, and a relatively
15 high critical temperature T_c . Joints formed according to the methods of the present invention are believed to provide good electrical and mechanical connectivity between the superconducting filaments of the joined wires, improved magnetic field tolerance of the joints as compared to conventional joints between similar wires, and protection against mechanical damage.

20

Fig. 2 illustrates an early step in a joining method of the present invention. Two conductors 12, 14 to be joined are stripped of their channel 5 over a certain length to expose the wires 7. A binding 18, for example of stainless steel wire, is wrapped around the two conductors in an unstripped region, to hold them mechanically
25 together. The channels 5 of the conductors 12, 14 may be soldered together in the unstripped region for further mechanical stability. A certain length 20 of each of the stripped regions of the wires 7 is bent to a radius r . The radius should be selected to be small, yet not so small as to risk degradation of the MgB_2 superconductor. With present MgB_2 wires, a radius of about 80mm – 100mm may be preferred. The bend
30 may be made to an angle θ preferably in the range 45° - 90° .

Fig. 3 shows a next stage in a method of the present invention, a retaining clip 22 is applied, to hold the bent portion 20 of wires 7 steady in position. The stripped wires 7 in the bent region are immersed in an etchant 24 within a bath 26. The material
35 and temperature of the etchant is selected with regard to the materials and the topology involved. The etchant is selected to remove the matrix 3 material, and to expose the sheaths 2 of the filaments 4.

In a typical example, the matrix 3 is of copper alloy, and the sheaths 2 are of niobium. An etchant 24 of nitric acid may be found suitable, as it etches copper but does not significantly attack niobium.

5

In other examples, molten tin (Sn) at a temperature of approximately 300°C may be found suitable. Cu and copper alloys dissolve readily in hot tin. In this case, the tin will simultaneously etch the copper matrix and form NbSn in a single step.

- 10 Use of hot tin is preferred, and acid etch is preferably used only for sheath materials which are not significantly reactive with hot tin or where the removal of the sheath material with tin would take too long.

Bath 26 must be chosen to be resistant to the etchant 24. In the case of a hot tin
15 etchant, the bath may be a crucible. An agitator 28 may be provided to cause circulation of the etchant 24 around and between the wires 7, and the sheathed 2 filaments 4.

Once etching is complete, reaction of the sheath 2 material is carried out. In a
20 crucible, which may be a crucible bath as used in the step of Fig. 3, the bent region 20 is immersed in hot tin (Sn) at a temperature of about 600°C. The elemental niobium (Nb) of the sheath 2 reacts with the hot tin (Sn) by diffusion to become Nb₃Sn, a superconductor. The rate of diffusion of Sn into Nb is highly dependent on the temperature of the molten Sn. Accordingly, the highest practicable temperature
25 for the tin is preferred. An inert gas or vacuum atmosphere may be provided to prevent oxidation of the tin.

Figs. 4A – 4C shows three cross-sectional views, each through a single sheathed 2
filament 4 illustrating progression of the reaction. In Fig. 4A, the MgB₂ core 1 is
30 enclosed within an unreacted Nb sheath 2, immersed in the Sn bath 24. In Fig. 4B, the sheath 2 has begun to react, and an outer part of the sheath has transformed into Nb₃Sn, while the inner part of the sheath remains as elemental Nb. Reaction continues by diffusion, until the sheath 2 is completely transformed into Nb₃Sn, as shown in Fig. 4C. The MgB₂ core 1 remains un-reacted.

35

The wires 7 are then removed from the crucible. Fig. 5 shows a partial cross-section of a single filament 4 following this step. The MgB_2 core 1 is unreacted. The sheath 2 is now entirely of Nb_3Sn and a thin Sn coating is present on the sheath, from the Sn wetting in the crucible. The grains of MgB_2 within the core are shown. Due to the manufacturing method of the filaments, the MgB_2 grains are in close proximity to the material of the sheath: this distance is typically less than the coherence length of Nb_3Sn , enabling a persistent superconducting joint to be made between MgB_2 cores, through the Nb_3Sn material of the sheath 2.

Fig. 6 illustrates a further step in a method according to the present invention. The bent portions 20 of wires 7, now comprising MgB_2 cores in Nb_3Sn sheaths, are placed within a further crucible or mould 28. Alternatively, the same crucible may be used, if of suitable construction. A superconducting casting material 30 such as Woods metal or PbBi is added to the crucible or mould 28, thereby immersing the bent portion 20 of filaments 4. To assist with mechanical alignment during casting, the retaining clip 22 may be left in place. To provide mechanical strength of the finished joint, adjacent parts of the wires 7 may also be cast into the casting material 30. The casting material is allowed to cool and harden. The resulting joint 40 is removed from the crucible or mould 28, as shown in Fig. 7.

20

It is important that the ends 32 of the filaments are not immersed in the etchant, or in the superconducting casting material to prevent damage to, or contamination of, the MgB_2 core.

Fig. 8 shows a cross-section through a part of the joint 40 illustrated in Fig. 7. Filaments 4 of each wire are shown, still grouped together. The filaments 4 are embedded within the superconducting casting material 30. Fig. 9 shows an enlargement of that part of Fig. 8 indicated at IX. The MgB_2 cores 1 of each filament 4 are mechanically attached, and electrically connected together, through superconducting Nb_3Sn sheath layers 2 and the superconducting casting material 30. The Sn coating shown in Fig. 5 has gone into solution in the superconducting casting material. An electric current i can pass from one core 1 of MgB_2 , through a sheath 2 of Nb_3Sn , a distance of superconducting casting material 30, another sheath 2 of Nb_3Sn , to the MgB_2 core 1 of another filament 4. In this way, the superconducting joint of the invention may be realised. There is no need to apply a mechanical load to the superconducting wires, reducing the risk of damage to the superconducting

filaments as compared to conventional joining methods which involve mechanical compression.

A variant of this method of forming a superconducting joint according to the invention
5 will be discussed with reference to Figs. 10.

In this embodiment, it is not necessary to bend the wires, allowing a more compact final joint.

10 Fig. 10 shows an end of a first wire to be joined. The matrix material such as copper or MONEL 3 has been etched away, for example using acid, over an end portion, leaving Nb-sheathed 2 filaments exposed. The ends 42 of the filaments are sealed before immersion in tin in the crucible. This may be achieved by welding or mechanical crimping of the matrix material.

15

During a crimping step, adjacent MgB_2 particles are crushed and fall from the filaments, leaving a length of empty sheath which may be sealed by crimping. Alternatively, welding, brazing or similar using a material which is unaffected by tin (Sn) at 600°C may be used to seal the ends of the filaments. Such sealing has the
20 objective of preventing the MgB_2 particles from coming into contact with the molten tin.

In the method of Figs. 3-7, the bend in the wires is provided to prevent immersion of the open ends of the sheaths in the etchant, the tin and the superconducting casting
25 material. By using straight wires with sealed ends, as shown in Fig. 10, the open ends of the sheaths are also protected from exposure to etchant or casting material. The crucible in which wires such as shown in Fig. 10 are cast into a joint may be much smaller than that shown in Fig. 7: for example, a narrow cylinder. A multi-part mould may be used to form moulding cavities for such joints, as crucibles may be
30 difficult to form and fragile in use if shaped as a narrow cylinder.

Superconducting joints formed as described above are believed to be suitable for application in the manufacture of dry magnets cooled by a cryogenic refrigerator to a temperature of about 10K. In such an arrangement, it is preferred that the
35 superconducting joints should be positioned close to the refrigerator, to ensure effective cooling of the joints.

An alternative method for forming superconducting joints will now be discussed, with reference to Figs. 11 and 12. This method shares the feature of causing reaction of the niobium sheaths of the filaments with tin to form Nb_3Sn superconducting sheaths. However, the resulting joint is crimped together, rather than being cast in a superconducting material.

Fig. 11(i) shows two wires 7 to be joined together according to a method of the present invention. The ends of the wires have been sealed at 44, for example by crimping, brazing or welding, with a material which is resistant to hot tin.

10

As shown in Fig. 11(ii), the matrices 3 are stripped over a certain length at their ends. The filaments 4 are thereby exposed. The material of the seals 44 must be resistant to any etchant used to strip the material of the sheath. The seals 44 prevent exposure of the MgB_2 cores to the etchant.

15

As illustrated in Fig. 11(iii), a cylindrical metal crimp 46, for example of niobium-lined copper tube is placed around the filaments. The niobium lining may be a coating on the inside of the copper crimp, or may be a niobium foil wrapped around the filaments, with a copper crimp then placed over the foil. The crimp should be a snug fit, but not tight, lest damage be caused to the filaments as the crimp is fitted. A mechanical crimping step is then performed, schematically illustrated by arrows 47. This presses the niobium lining of the crimp into contact with the niobium sheaths of the filaments, and presses the filaments into contact with each other. Although some mechanical compression of filaments 4 is involved, the MgB_2 cores 1 remain encased within the Nb sheaths 2, which reduces the risk of damage to the cores during mechanical compression, as compared to most conventional methods.

Fig. 11(iii)(a) shows a cross-section through the crimp at this stage. The outer surface 48 of the crimp shows mechanical deformations 50 due to the crimping process. The niobium lining 52 of the crimp 46 is to be seen. Within the crimp, the filaments 4 of the wires 7 are pressed together into mechanical contact. The crimping process must be controlled so as not to damage the MgB_2 cores of the filaments. At this stage, the MgB_2 cores 1 of the filaments 4 are electrically joined through niobium metal sheaths 2, and the niobium lining of the crimp.

35

Fig. 11(iv) shows a further stage in this method. The crimped filaments 4, as illustrated in Figs. 11(iii) and 11(iii)(a) are immersed in molten tin 54 within a crucible

56. The molten tin is at a temperature of about 600°C or more. This step may be performed in a vacuum, or in an inert atmosphere to prevent reaction of atmospheric components with the tin. As discussed with reference to Fig. 4, immersion of niobium sheaths 2 in such hot tin causes the niobium to react with the tin by diffusion to form superconducting niobium-tin (Nb_3Sn). Preferably, this reaction is performed at a suitable temperature, and for a suitable time, for the niobium sheaths 2 to completely transform to Nb_3Sn , but it is not necessary for the niobium lining 52 to completely transform to Nb_3Sn .

10 Fig. 12 shows a cross-section, similar to the cross-section of Fig. 11(iii)(a), of the resulting crimped joint. The outer surface 48 of the crimp shows mechanical deformations 50 due to the crimping process. The lining 52 of the crimp 46 has been converted to Nb_3Sn . Within the crimp, the sheaths 2 of filaments 4 of the wires 7 have also been converted to Nb_3Sn . They are pressed together into mechanical
15 contact. The MgB_2 cores 1 of the filaments 4 are electrically joined through Nb_3Sn sheaths, and the Nb_3Sn lining of the crimp. The Nb_3Sn components are superconducting, as discussed above, and have much better superconducting characteristics than niobium, for example in having a significantly greater field tolerance (about 18T at a temperature of 4K) and a higher critical temperature (about
20 18K). Nb_3Sn also has a relatively large coherence length. The copper crimp 46 is unaffected by immersion in tin, other than in gaining a tin coating.

While the resulting structure illustrated in Fig. 12 may be immersed in molten superconducting filler material such as Woods metal or PbBi , which infuses between
25 the filaments 4 and fills the crimp, it is preferred not to include such jointing material. The mechanical and electrical contact between Nb_3Sn sheaths and Nb_3Sn crimp lining layer provided by this embodiment of the invention may be sufficient to provide the required superconducting joint. The resultant joint between multiple Nb_3Sn connections without a filler material is expected to tolerate relatively high strength
30 magnetic fields and remain superconducting at temperatures in excess of 10K. Such joints are expected to be useful in the manufacture of dry magnets cooled by thermal conduction by cryogenic refrigerators operating at about 10K.

The present invention accordingly provides methods for joining superconducting
35 wires, and joints such as may be produced by such methods. The present invention relates to joints between filaments having a niobium sheath, such as

superconducting wires having MgB_2 cores, those having NbTi cores, and joints between a MgB_2 cored wire and a NbTi cored wire. According to the invention, the niobium sheaths are immersed in hot tin (Sn) so as to convert the niobium into Nb_3Sn , which is a superior superconductor to elemental niobium. The resulting
5 Nb_3Sn sheaths act as an efficient and effective conductor for introducing transport current into the MgB_2 cored wires. Magnetic field tolerance of the resulting joint is significantly improved as compared to conventional joining methods for such wires, in which it is thought that the niobium sheath carries some or all of the current flowing through the joint. The MgB_2 core is not exposed to the tin (Sn) during joint formation,
10 reducing the risk of contamination or oxidation of the MgB_2 core.

Some exposure of an MgB_2 core to hot tin may be tolerated, provided that the tin does not penetrate a significant distance into the wire so as to reach the effective part of the joint.

15

In some embodiments of the present invention, multiple joints may be formed in a single tin artefact. Each joint may be of two or more superconducting wires. In a variant of such embodiments, multiple joints may be formed in a single tin artefact, and the tin artefact may then be divided to provide separate joints.

CLAIMS

1. A method for joining first and second superconducting wires (7), each
5 comprising a number of filaments (4) which each comprise a superconductive core
(1) within a respective sheath (2), the filaments (4) being embedded within a matrix
(3), wherein the superconductive cores (1) comprises magnesium diboride (MgB_2)
and the sheaths (2) comprise niobium (Nb),
the method comprising the steps of:
- 10 - over a certain length (20), removing the matrix (3) to expose the filaments (4);
- immersing the exposed filaments (4) in molten tin (Sn) (24; 54) such that niobium of
the sheaths (2) is converted to niobium-tin (Nb_3Sn);
- providing a superconductive path between superconductive cores (1) of filaments
(4) of the first wire (7), through the Nb_3Sn sheaths (2) of the filaments (4) to the cores
15 (1) of the second wire (7).
2. A method according to claim 1 wherein the step of immersing the exposed
filaments in molten tin is performed using tin at a temperature of at least 600°C .
- 20 3. A method according to claim 1 wherein the step of immersing the exposed
filaments in molten tin is performed while preventing exposure of the cores (1) to the
molten tin (24; 54) in the effective part of the joint.
4. A method according to claim 3 wherein the wires (7) are bent prior to
25 immersion in molten tin, such that ends (32) of the sheaths (2) are not immersed in
the molten tin.
5. A method according to claim 4 wherein the bent wires are retained in fixed
relative positions by a retaining clip (22) during immersion in the molten tin.
- 30 6. A method according to claim 2 wherein ends (42) of the sheaths (2) are
sealed prior to immersion in the molten tin, such that cores (1) of the filaments (4) are
not immersed in the molten tin.
- 35 7. A method according to any preceding claim wherein the superconductive path
between superconductive cores (1) of filaments (4) of the first wire (7), through the
 Nb_3Sn sheaths (2) of the filaments (4) to the cores (1) of the second wire (7) is

provided by embedding the filaments of the first and second wires within a superconducting casting material (30).

8. A method according to claim 1 wherein the filaments (4) of the first and second wires (7) are retained within a crimp (46) during immersion in molten tin (54), such that, following conversion of the sheaths (2) to Nb_3Sn , electrical and mechanical contact is provided between Nb_3Sn sheaths of the filaments.

9. A method according to claim 8 wherein the step of retaining within a crimp comprises the sub-steps of:

bringing the filaments (4) of the wires (7) into close proximity;
placing a cylindrical crimp (46) around the filaments;
mechanically crimping (47) the crimp, to press the filaments into contact with each other.

15

10. A method according to claim 9 wherein the crimp is lined (52) with niobium, which is pressed into contact with the filaments as crimping is performed, and wherein the lining (52) is at least partially converted into Nb_3Sn during immersion in the molten tin, providing a further superconductive path between filaments.

20

11. A method according to claim 2, wherein an inert atmosphere is provided around the molten tin to prevent oxidation of the tin.

12. A joint between first and second superconducting wires (7), each comprising a number of filaments (4) which each comprise a superconductive core (1) within a respective sheath (2), the filaments (4) being embedded within a matrix (3), wherein the sheaths (2) comprise niobium (Nb), the joint itself comprising:

- a certain length (20) of filaments exposed by removal of the matrix (3);
- 30 - over the certain length, the sheaths (2) are of niobium-tin (Nb_3Sn);
- a superconductive path being provided between superconductive cores (1) of filaments (4) of the first wire (7), through the Nb_3Sn sheaths (2) of the filaments (4) to the cores (1) of the second wire (7).

35 13. A joint according to claim 12 wherein the superconductive cores (1) comprise magnesium diboride (MgB_2).

14. A joint according to claim 12 or claim 13 wherein ends (42) of the sheaths (2) are sealed.

15. A joint according to any of claims 12-14 wherein the filaments of the first and
5 second wires are embedded within a superconducting casting material (30), such that the superconductive path between superconductive cores (1) of filaments (4) of the first wire (7), through the Nb₃Sn sheaths (2) of the filaments (4) to the cores (1) of the second wire (7) is provided through the superconducting casting material (30).

10 16. A joint according to any of claims 12-15 wherein the filaments (4) of the first and second wires (7) are retained within a crimp (46), such that electrical and mechanical contact is provided between Nb₃Sn sheaths of the filaments.

17. A joint according to claim 16 wherein the crimp is lined (52) with niobium, at
15 least partially converted into Nb₃Sn, providing a further superconductive path between filaments.

FIG 1

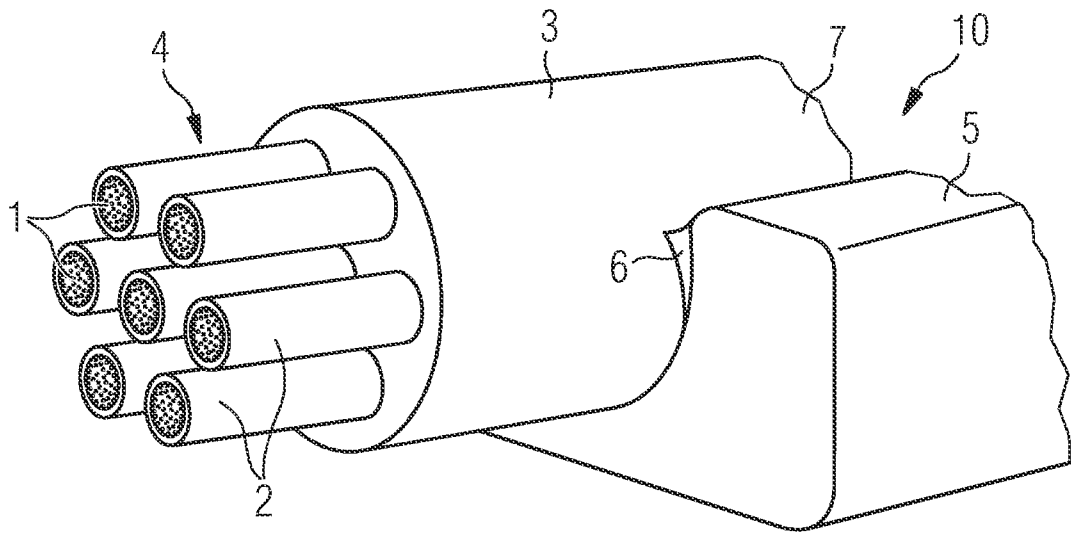
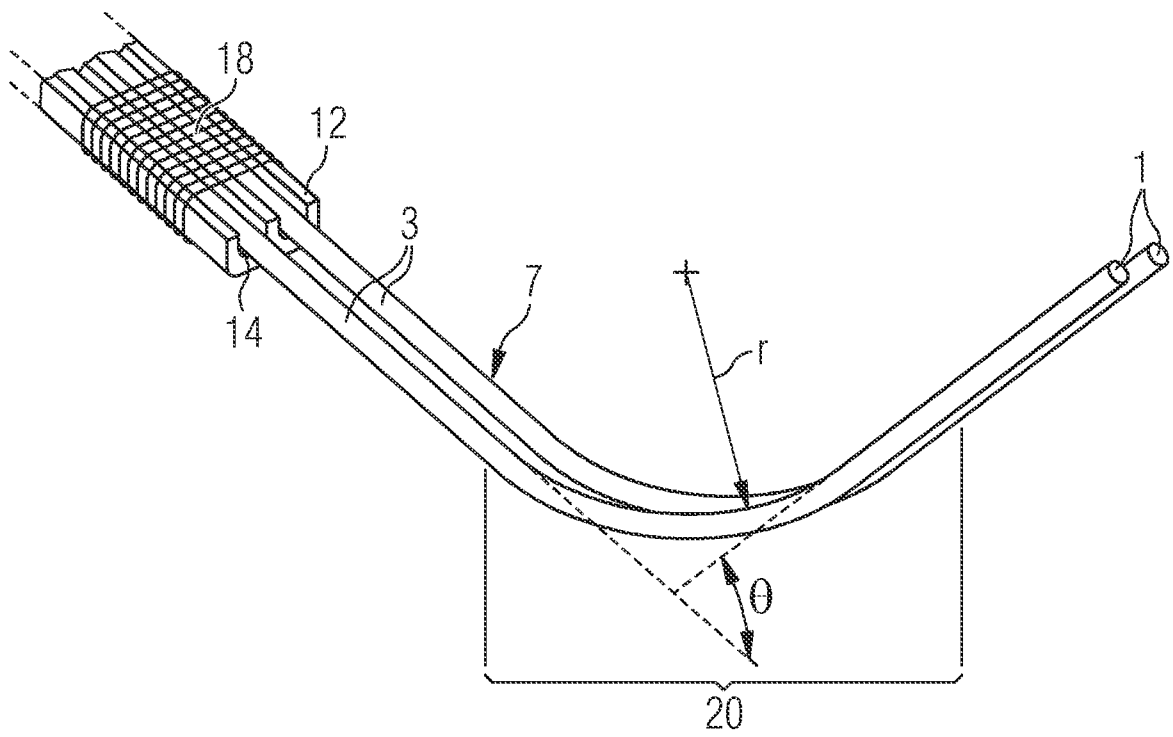


FIG 2



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FIG 3

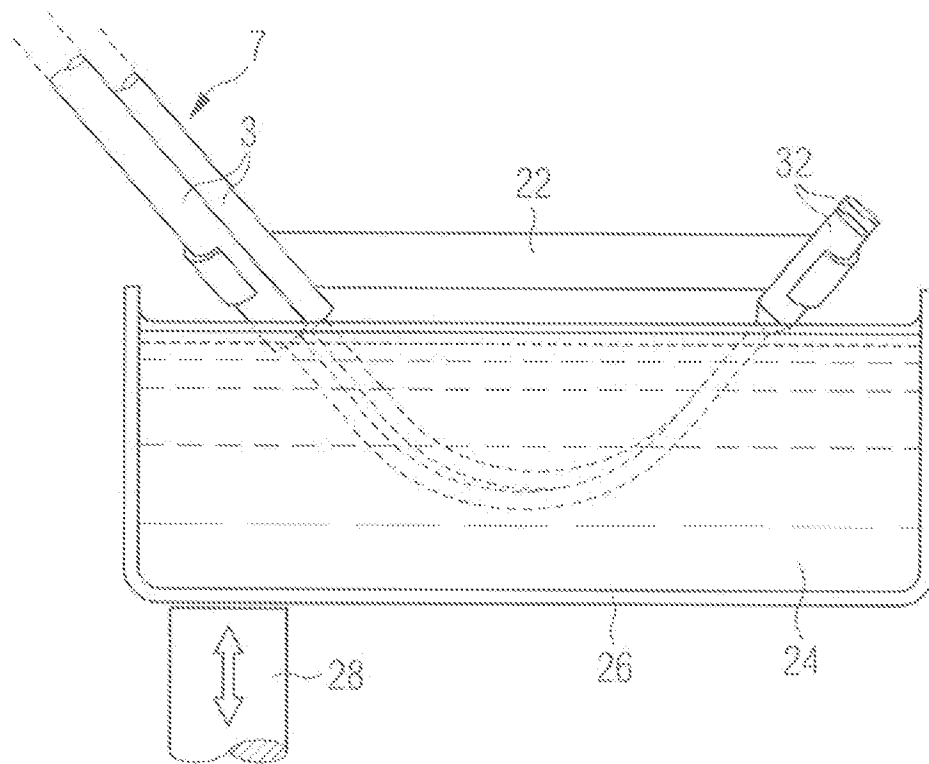


FIG 4A

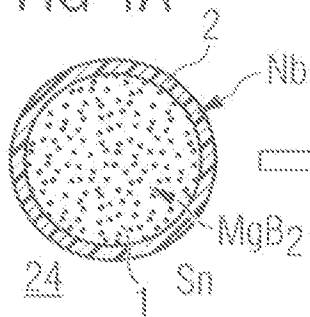


FIG 4B

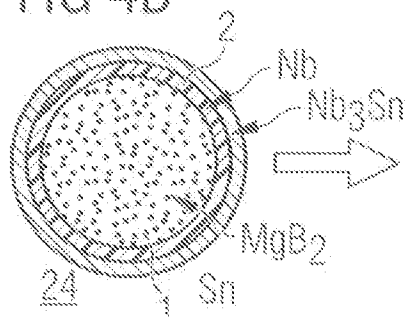


FIG 4C

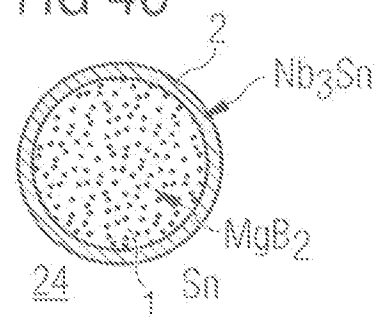


FIG 5

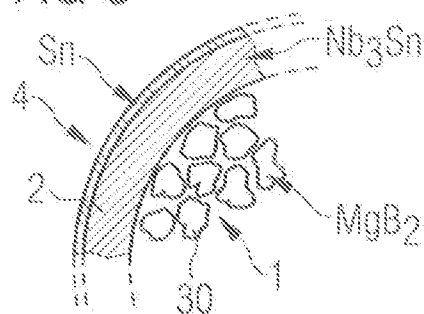


FIG 6

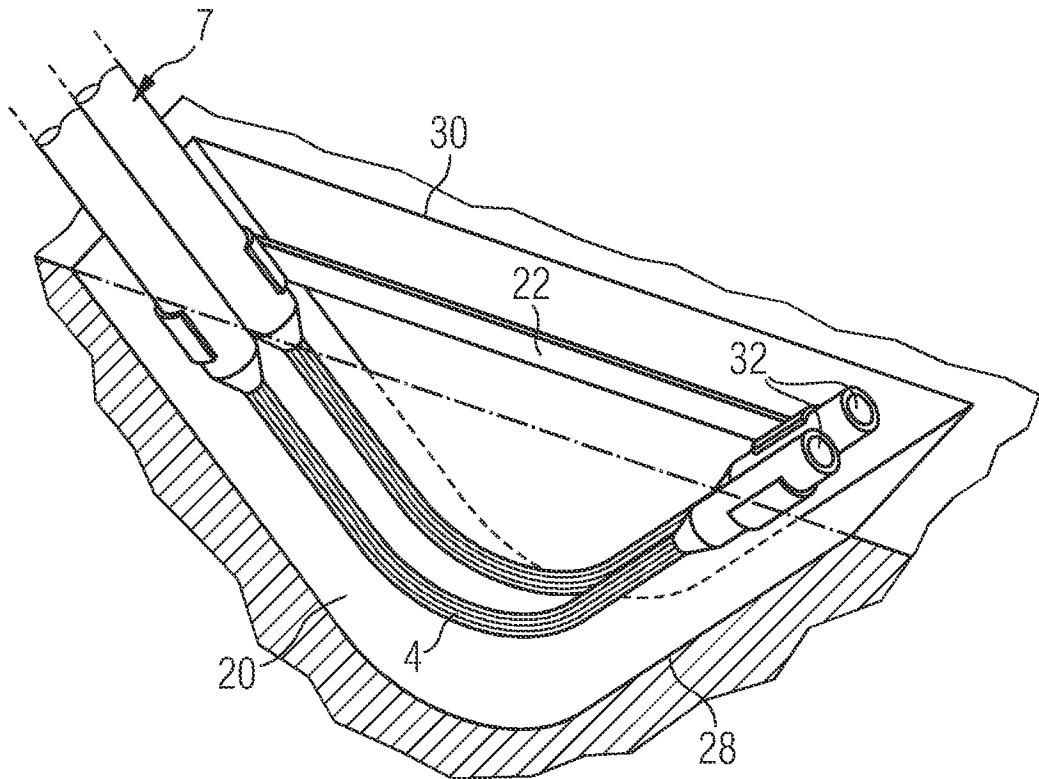


FIG 7

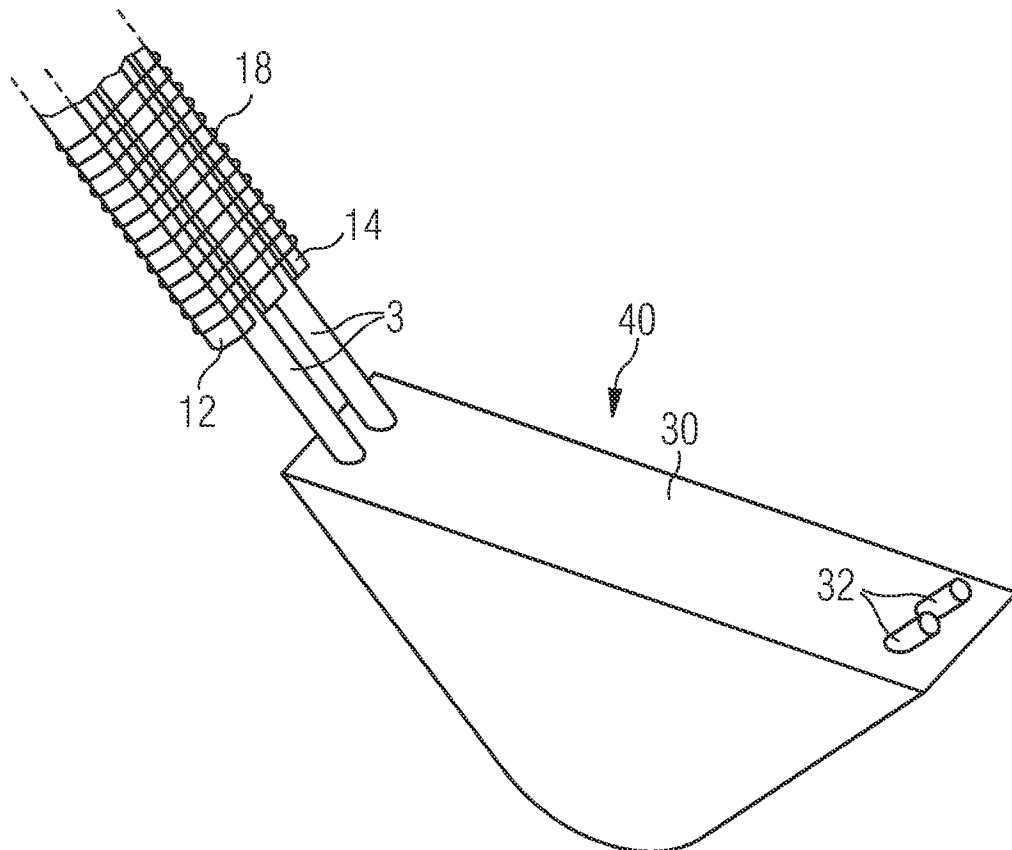


FIG 8

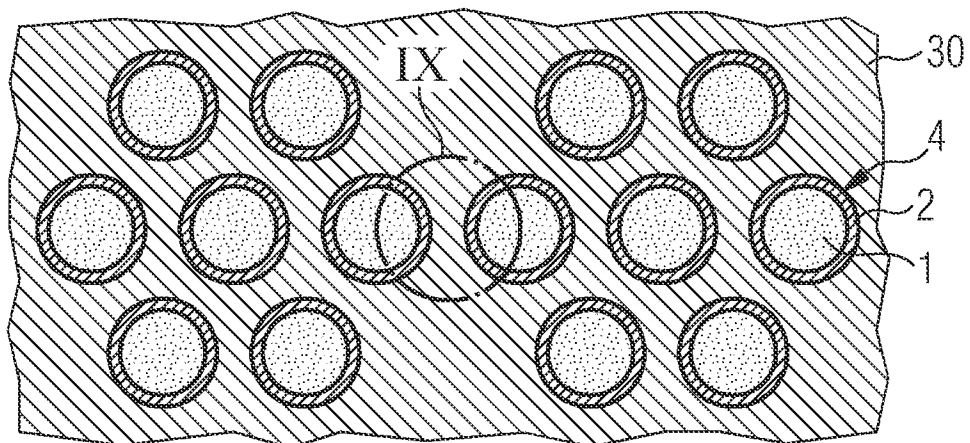
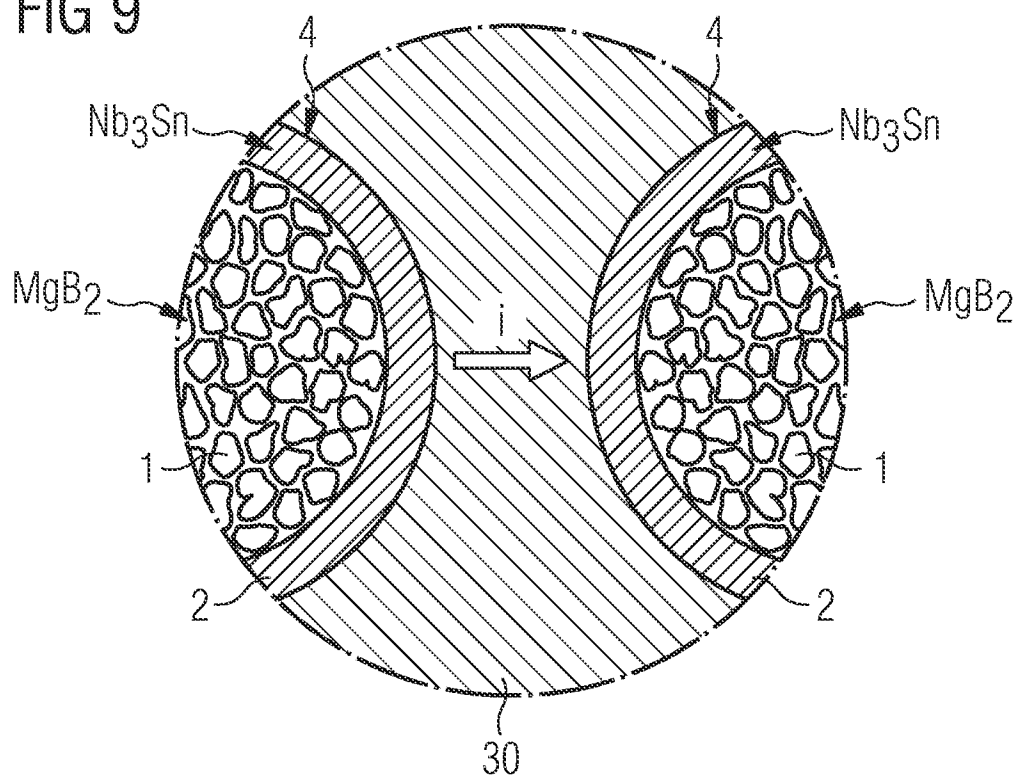


FIG 9



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FIG 10

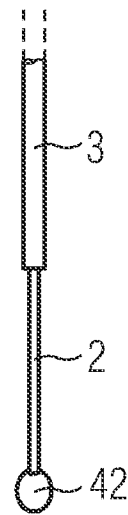


FIG 11

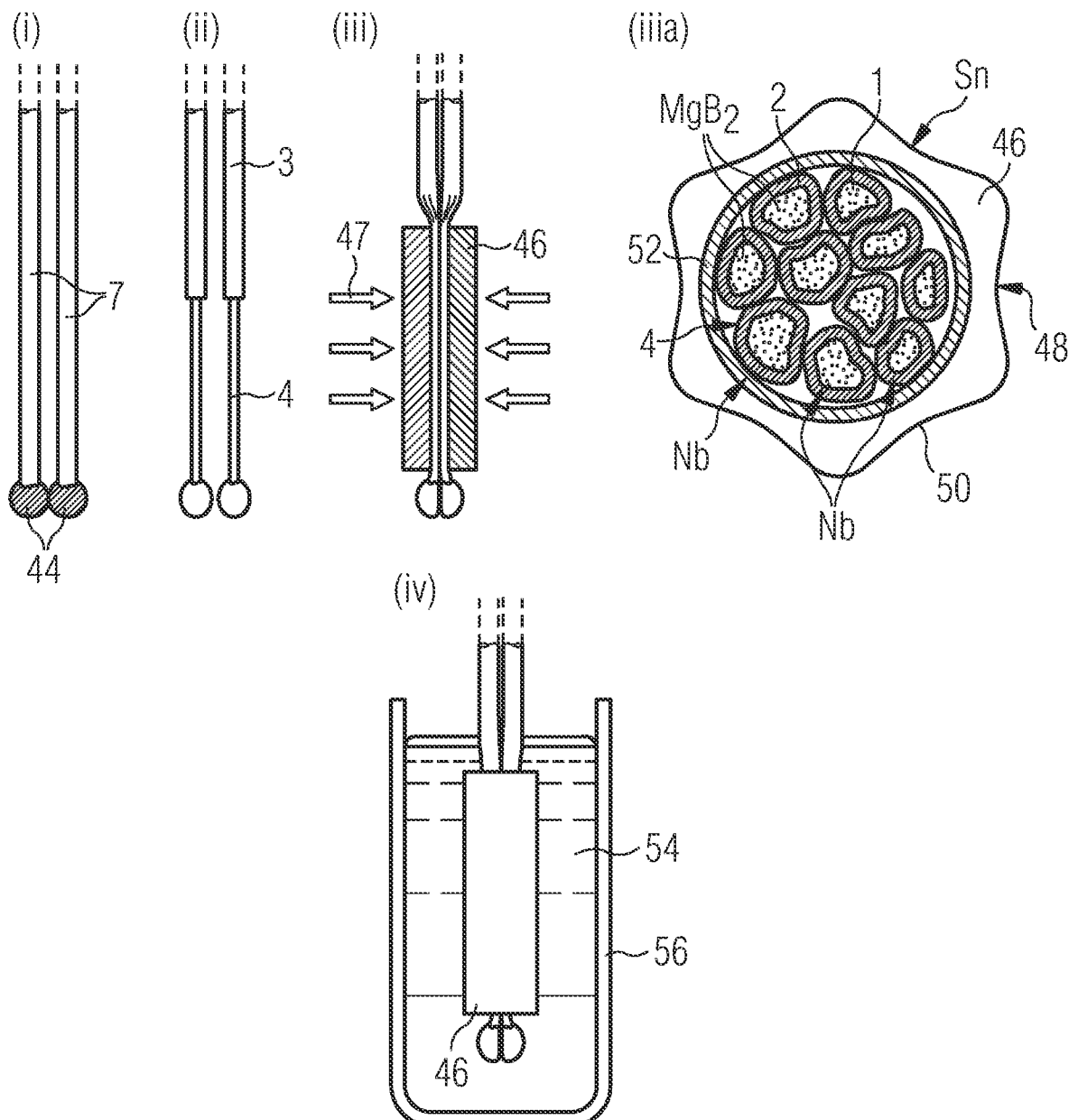
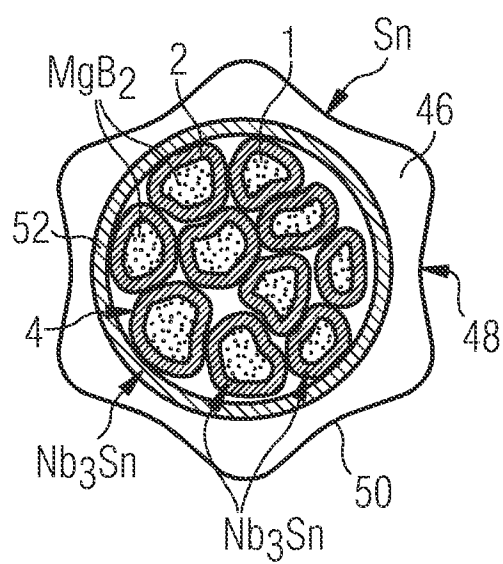


FIG 12



INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2011/052448

A. CLASSIFICATION OF SUBJECT MATTER

INV. H01L39/02

ADD.

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)

H01L

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)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2006/240991 A1 (TAKAHASHI MASAYA [JP] ET AL) 26 October 2006 (2006-10-26)	1-7, 12-15
Y	paragraph [0058] - paragraph [0080]; figures 6,7,8,13,14	8-11,16, 17
Y	JP 2 276180 A (MITSUBISHI ELECTRIC CORP) 13 November 1990 (1990-11-13) abstract	8-10,16, 17
Y	EP 0 148 479 A2 (GEN ELECTRIC [US]) 17 July 1985 (1985-07-17) page 9, line 32 - page 10, line 30	11



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

29 February 2012

Date of mailing of the international search report

14/03/2012

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Gröger, Andreas

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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