Lee Sears
NSF REU- NHMFL
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Abstract

The purpose of this project was to create a superconducting material known as magnesium diboride and then make wires out it. Based on published research, we know that the MgB_2 wires must be cold worked at least 68.75% before the material is dense enough to superconduct. Although initial attempts to cold work a stainless steel wire of MgB_2 was unsuccessful due to premature fracturing, we were able to eventually obtain the target percentage of cold working using a combination of heat treatment and slower rolling of the wires.

Introduction

Purpose:

To better understand how changing the conditions during the creation of MgB_2 affects its properties as a superconductor. Published research about MgB_2 wires by other research groups has found substantial differences in the temperature and length of annealing needed to achieve optimum superconducting properties in the wires. Furthermore, the current theories on what gives a superconductor its properties dictates that the addition of small amounts of impurities could increase the current density of the superconductor due to flux pinning. Therefore, we also studied how the addition of 5% wt. and 10% wt. Vanadium affected the current density of the wire compared to the pure MgB_2 for each heat treatment.

Properties of a Superconductor:

Many metals and compounds exhibit a phenomenon known as superconductivity at very low temperatures. The temperature at which a certain material becomes a superconductor is called the critical temperature (T_C). The values for T_C are typically below 100 K, although materials have been found with T_C's as high as 139 K. Superconductors get their name from the fact that below T_C they exhibit vanishingly small resistance. Currents induced in a super-conducting loop can have a decay time of as long as 100,000 years, meaning that a superconductor has effectively zero resistance.

Aside from remarkable electrical properties, superconductors also display some interesting magnetic phenomenon. The Meissner Effect, discovered by Walther Meissner and R. Ochsenfeld in 1933, is the ability of a material in the super-conducting state to repel magnetic lines of flux from its interior. The superconductor acts as a perfect diamagnet and, if a strong magnet is placed over a superconductor, the superconductor will levitate the magnet. In type II superconductors, like MgB_2, not all flux is repelled. Instead, small cylindrical tubes of normal state are forming in the superconductor through which magnet flux can penetrate. These tubes, or vortices, can move through the material but often get pinned against impurities in the crystal.

BCS Theory:

The most popular theory explaining the physics behind superconductors is known as the BCS theory. The theory states that as electrons move through the crystal lattice of a superconductor, they move in pairs called Cooper pairs. As an electron moves through a crystal, it creates a slight distortion in the positively charged lattice. This distortion can affect another electron causing the two to act as a pair. The average distance between two electrons that are not involved in a Cooper pair is about 100 times smaller than the

distance between the pair. The result of this is that for two electrons to act as a pair, all the electrons must move together. Imperfections that might deflect electrons and normally lead to resistance cannot do so without affecting all of the electrons. Thus a current in a superconductor does not dissipate like a current in a normal conductor.

Magnesium Diboride:

When Nagamatsu et al. announced the discovery of superconductivity in magnesium diboride (MgB2) in the journal *Nature* in March 2001, it renewed interest in a compound that had been used for years. Here was a surprisingly simple and inexpensive compound, one that had been commonly used in chemistry labs for half a century, that remains superconductive at temperatures as high as 39 degrees Kelvin. The MgB2 transition temperature is a record high for simple metallic compounds, and the discovery opened up the possibility of a new class of low-cost high-performance superconductive materials.

Magnesium diboride has a hexagonal close packed crystal structure consisting of hexagonal planes of boron atoms separated by planes of magnesium atoms. The magnesium centred above and below the boron hexagons (see figure). This structure is very similar to that of graphite: each carbon atom - which has four valence electrons - is bonded to three others and occupies all planar bonding states (the sigma bands). The remaining electron moves in orbitals above and below the plane to form pi bands. Boron atoms have fewer valence electrons than carbon so not all of the sigma bands are occupied. This means that lattice vibrations in the planes are much larger, which results in the formation of strong electron pairs. This results in a large coherence length of 50 Å for MgB_2 and, as a consequence, this compound is not afected by grain boundaries.

Experimental Procedure

Creating the Superconducting Wire:

The first step in creating 3.5 grams of MgB_2 is to weigh out samples of 1.85 grams of magnesium and 1.65 grams of boron; this will create an end mixture of the proper stoichiometric ratio. We used 3.5 grams of MgB_2 because this is the mass needed in order to obtain the proper density after rolling the wires and this density value was obtained from published research. The next step is to grind the mixture using a mortar and pestle for twenty minutes. Once the powder is thoroughly mixed it is packed into a quarter inch diameter to stainless steel sheath that is 10in. long. This stainless steel tube has been threaded on both ends and screws are inserted on both sides to act as end caps. The wire is then rolled using a Stanat rolling mill. We start the rolling process at groove 15 and adjust the vertical height of the separation in increments of 10 starting at 30 and ending at 60. This process is repeated until groove 9, where we start making vertical height adjustments in increments of 2.5.

Initially we used a Monel sheath to roll the MgB_2 wires because this material was readily available in the CAPS building. Another advantage to using the Monel was that it allowed us to practice rolling wires on the rolling mill before we started with the actual stainless steel sheaths. Once we had rolled the Monel to a sufficient length we then began to use the stainless steel sheaths in the rolling process. Stainless steel is the preferable sheathing material for the MgB_2 because the stainless steel has very little reaction with the MgB_2 when annealed relative to the Monel. Furthermore, the material properties of the stainless steel lends itself well to the wire drawing application and it is

the most widely used sheathing material used by other researchers working on MgB_2 found in published articles to date.

Results

Our initial attempts to roll a wire using the monel was very successful. Although we went through the rolling process rather quickly (i.e. 8 hours) we found that we were able to cold work the 10 inch sheath by 67% before the onset of fracture. The final length of the monel wire was 41.25 inches and the final diameter was 2.1mm. Encouraged by these results we began to roll the MgB_2 using the stainless steel sheaths and a similar eight hour rolling process. However, the process did not go as smoothly as it did with the monel sheath and fracturing occurred after cold working the wire only 47% (3.4mm final cross-sectional diameter). This is a problem because of the density dependency of the superconducting properties of MgB_2.

Our initial idea was to heat treat the stainless steel wires after they had been rolled but just before the onset of fracture. We believed that heat treating the wire would decrease the dislocation densities that is a direct result to cold working. These dislocations impede the planes of stainless steel from sliding across one another thereby hardening the material (i.e. work hardening). Heating the cold worked sample gives the dislocated atoms the energy needed to move back to their normal position in the lattice – a more energetically favorable position. After heat treating a cold worked sample of MgB_2 for 9 hours at 575°C we found that we were able to continue rolling the stainless steel sample well past the point where fracturing occurred on the non-heat treated sample.

Using the heat treatment we were able to cold work the wire 61%. Although this is closer to 68% cold working that we need it still has not met this level yet.

Conclusion

Although initial attempts to cold work a stainless steel wire of MgB_2 was unsuccessful due to premature fracturing, we hope to be able to eventually obtain the target percentage of cold working using a combination of heat treatment and slower rolling of the wires. Initially we used a Monel sheath to roll the MgB_2 wires and once we had rolled the Monel to a sufficient length we then began to use the stainless steel sheaths in the rolling process. Stainless steel is the preferable sheathing material for the MgB_2 because the stainless steel has very little reaction with the MgB_2 when annealed relative to the Monel. Encouraged by these results we began to roll the MgB_2 using the stainless steel sheaths and a similar eight hour rolling process. We believed that heat treating the wire would decrease the dislocation densities that is a direct result to cold working. After heat treating a cold worked sample of MgB_2 for 9 hours at 575°C we found that we were able to continue rolling the stainless steel sample well past the point where fracturing occurred on the non-heat treated sample. Using the heat treatment we were able to cold work the wire 61%.