NUCLEAR FUSION USING SUPER CONDUCTIVE MATERIAL AS A POWER SOURCE

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Abstract

Nuclear fusion, a process that could supply the world with endless energy with no harm to the environment, proposes a solution to our growing population and damaged planet. The process involves two isotopes of hydrogen, tritium and deuterium, which fuse together to form helium and release energy in the process. Because fusion converts a neutron from mass to energy as modeled by Einstein's $E=mc^2$ equation, the energy released during fusion can be larger than any other source used today. To achieve this, superconductors are used to create a magnetic field that suspends the materials until they reach the required temperature to turn the material into its plasma state. This plasma state allows the two atoms to collide and complete the fusion reaction.

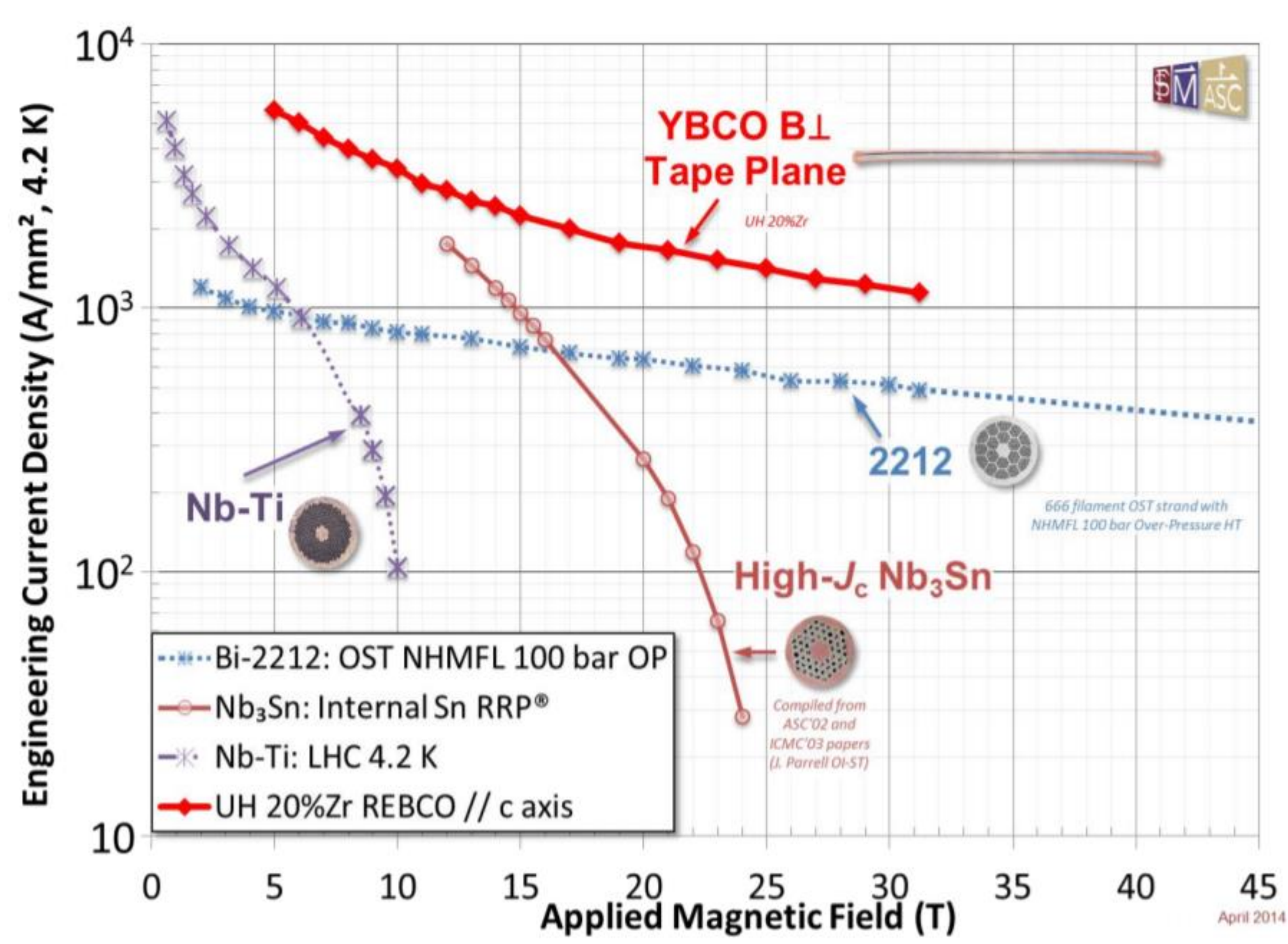
The Stellarator, a technological device engineers are developing in Greifswald, Germany, uses the process previously explained to create and harness energy for further use. Within devices used for harnessing this energy, a magnetic field must be created in order to suspend the plasma and ensure no contact between plasma and the carbon lining. Then, while controlling the temperature via microwaves and pressure within the vacuum tube, the plasma can be condensed and atoms with a high enough velocity fuse. With superconducting materials currently in use, engineers have reached a threshold where the magnitude of the electric field confining the plasma is constrained by current. ReBCO (Rare earth Barium Copper Oxide) is a super conductive technology that allows for higher currents and larger magnetic fields. Larger magnetic fields condense the plasma tighter and force more particles to collide. The evolution of more advanced superconductors will enable the Stellaraor to create massive amounts of energy for the current generation, as well as generations to come.

Background

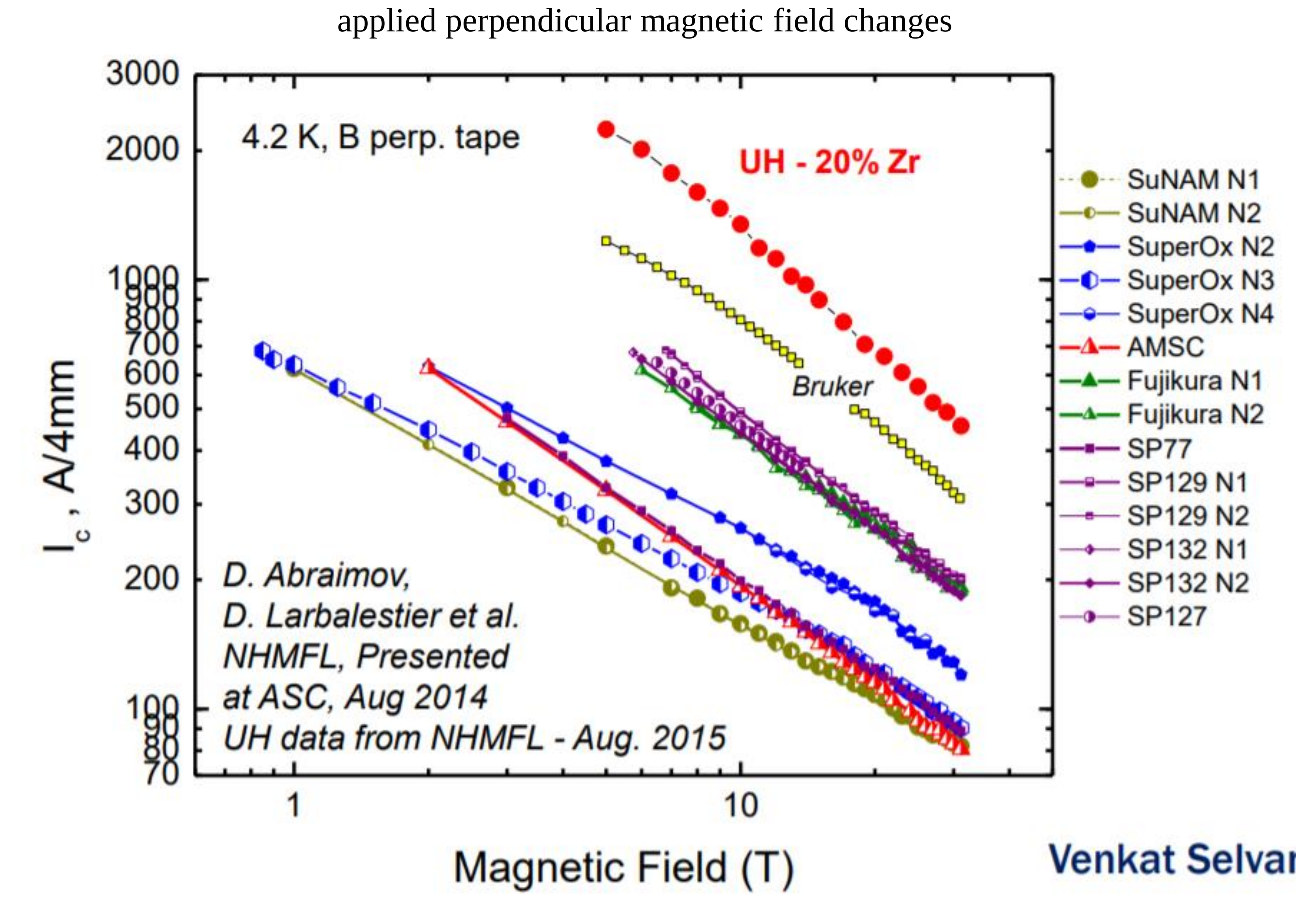
Nuclear fusion is a process that allows for an extreme magnitude of energy to be created with minimal pollution to the environment. In nature, a process where the nuclei of small atoms collide in a reaction to bind together occurs, forming a super nucleus. When this occurs, large amounts of energy are released. When fusion takes place between deuterium and tritium, two isotopes of hydrogen, the energy produced is at its maximum. Unfortunately, the process of nuclear fusion has its complications and difficulties. The system must meet the necessary conditions in order for fusion to occur. The nuclei must be at the exact right speed and orientation in order to collide together. Because of how intricate the process of the two nuclei coming together must be, many total collisions must occur to be successful. This produces a large amount of energy that can be harnessed for use.

Wendelstein 7-x

The Wendelstein 7-x, built in Greifswald, Germany and completed in 2015, uses a much greater amount of power than it produces. Its purpose is to test the feasibility of the technology and its various components as it relates to power generation. A Stellarator tries to replicate the extreme conditions inside the core of a star, an environment which is completely unlike any of which naturally occurs in this solar system outside of the Sun. It does so by using superconducting magnets to produce a magnetic field which suspends a plasma where the fusion reaction takes place. The magnets are submerged in a bath of liquid helium in a cryostat to keep them as cold as possible. The plasma's extremely high temperature - in the region of 100,000,000 Kelvin - means that there is no known material which can confine it, which is why it must be suspended magnetically in a vacuum. The plasma is heated up by 10 Megawatts of microwaves, which would result in 80 Megajoules of energy heating up the plasma.



Graph of the variations in critical current as applied perpendicular magnetic field changes



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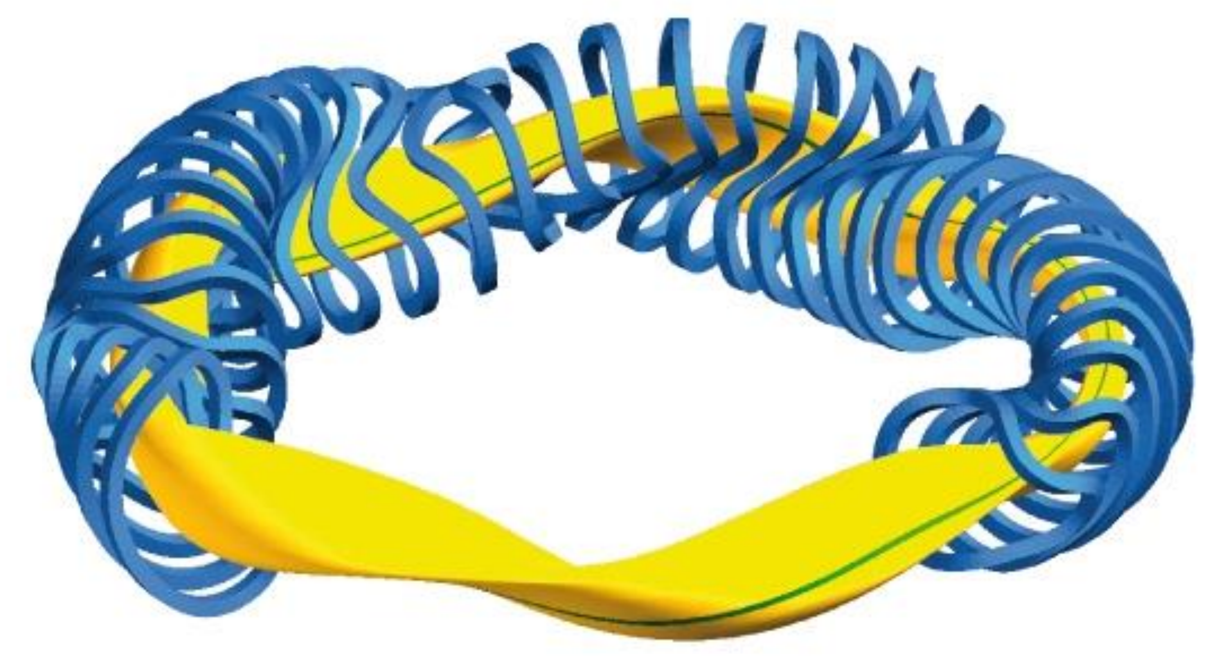
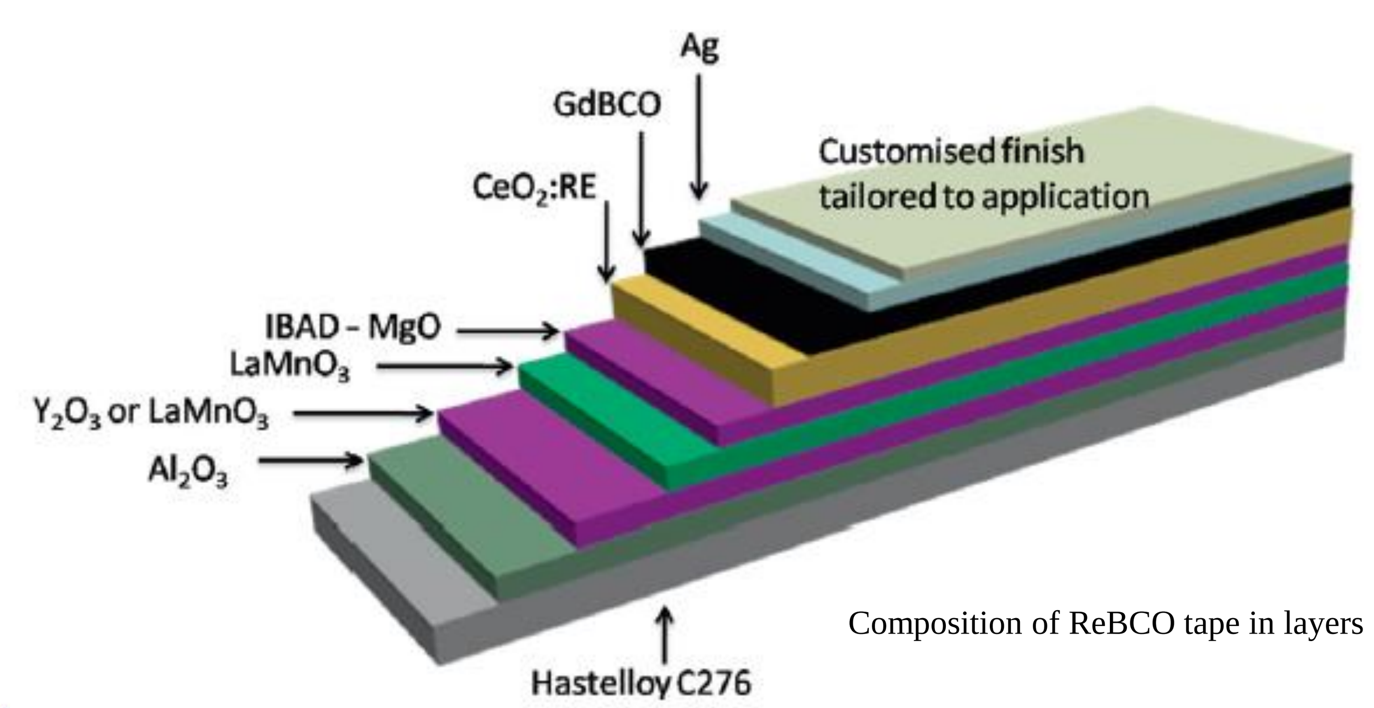


A computer illustration of the plasma (yellow) and the magnets (blue) in the Wendelstein 7-x

Superconductor to Intensify Stellarator Electromagnets

Given the importance and functionality of magnetic fields in nuclear fusion processes, to advance this technology it is necessary to have more powerful electromagnets. Besides suspending the plasma, the magnetic fields have the job of confining the plasma. With increased confinement, high temperature plasma has an increased probability of fusion and therefore higher reaction frequencies and ultimately the production of more power. Basically, magnets are crucial in creating reactors that are efficient and sustainable. The magnetic fields created within the Stellarator are produced with coils of superconductive materials that, when exposed to large current and low temperatures, produce high magnitude magnetic fields. Though we currently use superconductive materials that can facilitate nuclear fusion in its earliest stages, we have reached a barrier. Rare-Earth-Barium-Copper-Oxides (ReBCO) holds promising solutions with increased current density, critical current, resistance to magnetic field degradation, (relatively) high temperature performance capabilities, affordability and tolerance to mechanical stress and strain in environments with increased pressure and forces.



Composition of ReBCO tape in layers

Sustainability

This power source presents itself as the only truly sustainable option for massive energy production for decades to come. The future of nuclear fusion depends on global efforts and efficient funding and research. Developing nuclear fusion to a point where it is a reliable and efficient energy source could decrease the waste from alternative power sources, subsequently benefiting the environment. Overall, while the future of the Stellarator and other forms of nuclear fusion power may seem unattainable, efforts from scientists and nations across the globe could allow the dreams of many scientists to become a tangible reality.

The biproduct of nuclear fusion is not useless; it can be collected, processed and recycled. The technique involved heating the waste in order to enable the separation of the molecules and hydrogen isotopes. Palladium silver alloy membranes, which are only permeable by the hydrogen isotopes, can be used to collect the tritium via carrier gas in the form of tritiated water vapor. The vapor will collect within tubes of the membrane, allowing only the hydrogen isotopes to pass through to the other side. This process not only rids the environment of the waste produced, but even increases the efficiency and cost of the nuclear fusion devices. The recollection of tritium allows for reuse, and the advancements made to the process have made the process efficient and cost effective.

Additionally, the radioisotopes produced by fusion have an average half-life of less than ten years, ensuring that the radioactivity of the material will have diminished to a completely safe amount within 100 years, significantly faster than those produced by fission.

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