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# THEORETICAL FRAMEWORK AND PRACTICAL UTILIZATION OF HIGH-TEMPERATURE SUPERCONDUCTORS

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***Abstract:*** *In 1911, Kamerlingh Onnes and Holst found superconductivity in mercury at a temperature identical to fluid helium (4.2 K). After almost 50 years, the BCS hypothesis — a tiny clarification of superconductivity — was created in 1957. Various superconducting materials with change temperatures as high as 23 K have been found after the revelation. In 1986, Bednorz and Müller made a huge revelation in the field when they distinguished another group of superconductors known as cuprate high-temperature superconductors, which had change temperatures as high as 135 K. This surprising tracking down started new exploration in the fields of material science, essential physics, and innovation applications. This compact outline covers the principal physics of both customary low-temperature and high-temperature superconductors, alongside a concise outline of applications going from high-ability to low-control electronic gadgets. A short outline and forthcoming troubles are given toward the end, trailed by some application thoughts.*

***Keywords:*** *High temperature superconductors, physics HTScs applications, theories.*

## 1. Introduction

Solid or non-solid materials are referred to as high-temperature superconductors (HTSCs), because unlike normal superconductors, their superconductivity is not derived from the electron-phonon interaction. It generally happens in ceramic materials rather than metallic ones. While pair creation (called "Cooper pairs") of electrons is undoubtedly the cause of superconductivity, the fact that d-wave pairing predominates rather than traditional singlet pairing points to nontraditional electronic mating mechanisms. Over 25 years have passed with no explanation for the cause.

The transition temperatures (Tc) of high-temperature superconductors are often much greater than those of regular superconductors, hence the name. The temperatures reach 203 K, which is already within the range of ordinary superconductors' operating temperatures and roughly 180 K higher. A novel, unexpected class of high-temperature superconductors was discovered in Japan in 2008: compounds of iron, lanthanum, phosphorus and oxygen can be superconducting. According to Pnictogen Phosphor, these superconductors are called iron pnictides.

The fraction of iron atoms was unexpected since, in the presence of high enough magnetic fields, all other superconducting materials become ordinarily conducting. These high magnetic fields within the body could even be necessary for superconductivity. The degree of conjecture around the physical principles has increased. As per the BCS theory, it is evident that electron pairs are responsible for carrying the current flow. It is unknown, nevertheless, what impact unites these Cooper pairings. It seems rather likely that there is no electron-phonon interaction, unlike in metallic superconductors. The transition temperature may be raised from the initial 4K to at least 56K by selecting other admixtures, such as arsenic.

### 1.1. Utilizing Superconductors at High Temperatures

If at all feasible, high-temperature superconductors should be run at 77 K, as long as the current density is low enough to avoid exceeding the transition temperature. Using liquid nitrogen for adequate cooling is very cost-effective. These kinds of applications are found in cables and metrology. Nevertheless, the low current density is not always possible because of the very irregular current distribution throughout the cross section.

The HTSC has to be cooled more forcefully in applications with greater current densities, but maybe only in rare instances. The temperature has to be decreased to attain the same performance data as typical superconductors, such niobium-titanium.

Liquid nitrogen cooling has long been used with SQUIDs, which allow measurements of even minute changes in magnetic fields. But when the temperature rises, the signal's noise level also rises. For this reason, modern electronics would not often use a superconducting material at ambient temperature. Although high-temperature SQUIDs produce more noise than those using earlier helium technology, they are nevertheless present and unfavorable but are often tolerated due to the advantages of nitrogen cooling in terms of handling and cost.

The primary drawback of ceramic materials used in high-temperature superconductors is their brittle nature. However, by pouring the ceramic material into silver tubes and rolling them into flexible bands, a flexible conductor material has been created. As part of a pilot project, the city of Essen has been using a 1 km long underground cable that is only nitrogen-cooled and designed to operate at 10 kV in the medium-voltage network since May 2014. It takes the place of a standard 110 kV ground line.

## 2. Literature Review

**Maksimov, E. G. (2000).** We audit the flow status of understanding the electrical premise of high-temperature superconductors, with specific accentuation on theories that are predictable with exploratory reality in copper oxides. A degree of understanding open to non-experts is given with respect to key inconsistencies, for example, the curiously huge damping of the electrons (or openings). The relationships between's superconducting temperature and damping are illustrated, rather than the heartlessness toward the electron thickness of states. We check out at expected hypothetical clarifications for the accompanying peculiarities: microwave surface opposition of cuprates, infrared conductivity, the Corridor impact, turn vulnerability, Raman spectra, NMR unwinding, and the Knight shift.

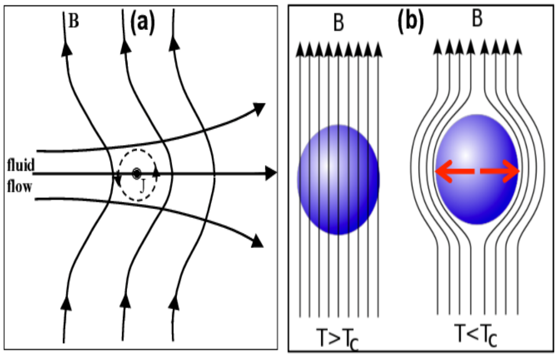
**Mourachkine, A. (2002).** A review is conducted on the theoretical and experimental research related to high-temperature superconductors, namely cuprates. A thorough examination of the state of the field's understanding indicates that superconducting cuprates behave very similarly to "conventional" metals in their normal state. Strong relaxation processes are shown to exist in the low-energy normal state of HTSC systems via experimental data. Numerous characteristics of low-energy relaxation processes in HTSC systems may be explained by the electron-phonon mechanism, according to ab initio simulations of the optical spectra and the electron-phonon interaction (EPI).

**Wesche, R. (2013)** Since its discovery twenty years ago, high-temperature superconductivity in copper oxides has prompted a broad search for knowledge about and applications of this novel state of matter. These materials have been seen as "exotic" superconductors from the beginning, while the word "exotic" may have several connotations. They have proven to be exotic in almost every sense of the word, as seen by the range of work that has been done. They display spectacular expressions of fluctuating superconductivity, new states of matter (d-wave superconductivity, charge stripes), and serve as a major source of inspiration and testing ground for novel experimental and theoretical methods.

**Bonn, D.A., (2006)** Basic temperatures have been expanded to 90 K in $YBa_2Cu_3O_7$ and 110 and 125 K in Bi-based and Tl-based copper oxides, separately, after Bednorz and Müller found superconductivity over 30 K in the La copper oxide system. To get a comprehension of the electrical qualities of these materials, numerous electronic construction calculations have been acted in the two years following this Nobel Prize-winning disclosure. These estimations, which are for the most part of the thickness utilitarian kind, are gathered, examined, and the results are contrasted and appropriate trial information in this review.

## 3. Meissner Effect

The discovery of a magnetic phenomenon in 1933 by Walter Meissner and Robert Ochsenfeld represents a basic aspect of superconductivity. This occurrence demonstrated that superconductors are not only excellent electrical conductors but also had the intriguing magnetic feature of being magnetically inert. A magnetic field cannot enter the inside of a superconductor. One of the most striking and simple characteristics of superconductors is this phenomenon, known as the Meissner Effect.




Superconducting transition temperature (T > TC) is shown in Figure 1. b) The Meissner Effect causes magnetic field lines to be ejected from the superconductor's core when it is cooled below its critical transition temperature (T < TC).

## 4. CONVENTIONAL SUPERCONDUCTIVITY THEORIES

### 4.1. Theory of London

F. and H. London provided the first theoretical model to explain the superconducting characteristics in 1935. To explain the zero resistance and the magnetic flux line exclusion, they created two equations. According to London's calculations, above a certain "penetration depth" λ, magnetic field lines enter the superconducting material but decay exponentially inside the superconducting sample. It was shown by A.B. Pippard that the surface current flowing at a certain location would depend on the magnetic field within a specific distance, which is referred to as the coherence length (ξ). The exact relationship between a superconductor's current density and magnetic vector potential is established by the London and Pippard equations.

### 4.2 Theory of Ginzburg-Landau

Ginzburg and Landau presented this hypothesis in 1950. The authors used Landau's theory of second order phase transition to explain the thermodynamic features of superconductors using this theory. Two equations were developed by Ginzburg and Landau to represent the order parameret! γ2! density of superconducting electrons as well as the superconducting current. The solutions to these equations provide several characteristics of superconductors, including the "coherence length" (ξ) of the material, which is a distinctive minimum length over which the wave function may vary considerably. The distinction between type-11 superconductors (ξ<λ) and type-1 superconductors (ξ >λ) was also provided by this theory.

### 4.3 Bcs Theory

The goal of developing a microscopic model that explained how a substance might show no electrical resistance or completely eradicate a magnetic field gave rise to BCS theory. Bardeen, Cooper, and Schrieffer put up this idea in 1957, and it was ultimately responsible for their 1972 Nobel Prize in Physics. The theory of BCS describes the electron-phonon interactions and how they react to superconductivity. These interactions may result in an electron-electron attraction to create a Cooper pair. Due of the Froehlich interaction, cooper pairs arise. These cooper couples have opposing spins and linear momentum due to the phonon, or lattice vibration, which also enables them to overcome the coulomb repulsions between them. Because of this, they may be regarded as a single, zero-spin particle, defying the Pauli exclusive principle. Every electron would be in a cooper pair at absolute zero. Because the electron pairing causes the material to enter a new, lower energy state known as the boson state, which in turn lowers the Fermion density of states, it is advantageous.

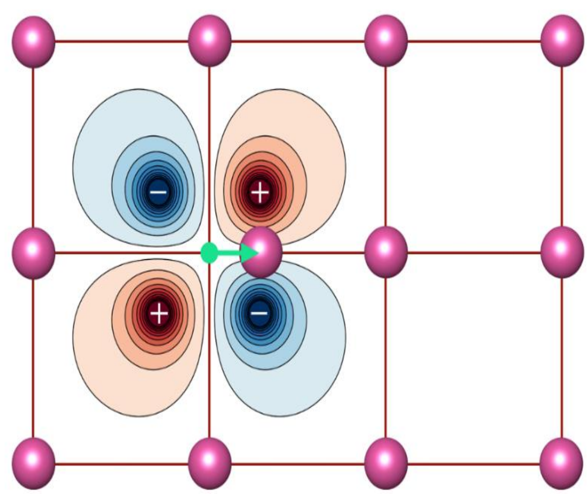



Figure 2: Electron- Phonon- electron interaction

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## 5. High Temperature Superconductors' Physics

Numerous families of cuprate HTS superconductors have been found thus far. They are all made up of layers of insulating material sandwiched between layers of CuO2. The CuO2 layers, which contain superconductivity, receive charge carriers from the insulating layers, which serve as charge reservoirs.

The discovery of cuprate superconductors was not coincidental, as many scientists contend; rather, it was born in light of the hypothesis that an exceptionally impressive electron-cross section cooperation is expected for high Tc values. Albeit some could battle that the BCS hypothesis as of now resolves this issue, there are various issues with this hypothesis, like the coupling between the transporters and the cross section, how much free transporters, and the relationship of the grid recurrence. Thusly, Tc is clearly limited, thus high temperature superconductivity can't be integrated into the BCS plot. Notwithstanding, Bednorz and Müller saw that various oxide superconductors had exceptionally low transporter densities regardless of having very high Tc values. They reasoned that this required a coupling between the transporters and the cross section that is remarkably enormous and outside the limits considered by BCS hypothesis. They suggested that the system behind such a solid relationship may be polaron development, and explicitly the idea of Jahn Teller polarons. The grid twisting cloud and the transporter in the outline consolidate to shape another substance known as a polaron, a semi molecule that can get across the cross section. Dissimilar to the customary Cooper pair, two of these semi particles consolidate to shape a bipolar on which superconductivity is just delivered by a relationship across a couple of nm. Along these lines, a given volume contains less pairings, and it is improbable that any of them would cover.

The hypothesis that high levels of Tc need a very strong electron-lattice interaction. Some might argue that the BCS theory already takes care of this problem; nevertheless, this theory has several drawbacks, including the interdependence of the lattice frequency, the amount of free carriers, and the coupling between the carriers and the lattice. As a result, Tc is clearly limited, which means that high temperature superconductivity cannot be included in the BCS method. On the other hand, Bednorz and Müller noted that several oxide superconductors had a rather high Tc value while having a very low carrier density. They came to the conclusion that this required an unusually significant coupling between the carriers and the lattice, which is beyond the parameters taken into account by BCS theory. They postulated that polaron creation, and more especially the idea of Jahn Teller polarons, may be the mechanism responsible for such a strong connection. In the diagram, the carrier and the lattice deformation cloud combine to generate a new entity called a polaron, which is a quasi-particle that may move across the lattice. Two of these quasi-particles join to form a bipolar on which, unlike the normal Cooper pair, is correlated across a few nm only in order to produce superconductivity. As a result, there are fewer pairings in a given volume, and it is improbable that any of them would overlap.from the hypothesis that high levels of Tc need a very strong electron-lattice interaction. Some might argue that the BCS theory already takes care of this problem; nevertheless, this theory has several drawbacks, including the interdependence of the lattice frequency, the amount of free carriers, and the coupling between the carriers and the lattice. As a result, Tc is clearly limited, which means that high temperature superconductivity cannot be included in the BCS method. On the other hand, Bednorz and Müller noted that several oxide superconductors had a rather high Tc value while having a very low carrier density. They came to the conclusion that this required an unusually significant coupling between the carriers and the lattice, which is beyond the parameters taken into account by BCS theory. They postulated that polaron creation, and more especially the idea of Jahn Teller polarons, may be the mechanism responsible for such a strong connection. In the diagram, the carrier and the lattice deformation cloud combine to generate a new entity called a polaron, which is a quasi-particle that may move across the lattice. Two of these quasi-particles join to form a bipolar on which, unlike the normal Cooper pair, is correlated across a few nm only in order to produce superconductivity. As a result, there are fewer pairings in a given volume, and it is improbable that any of them would overlap. Applications of HTSCs Here we sight some important application of HTSCs. Here using HTSCs instead of Low temperature semiconductors becomes important because of the feasibility of the former. It is always easy to create a superconductor at 122K than at 12K.

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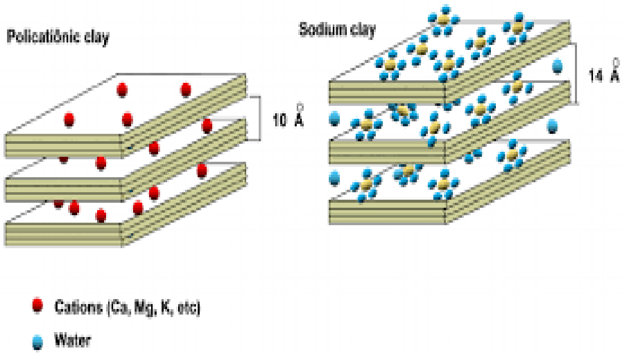


**Figure 3:** A cuprate HTS superconductor's schematic structure.

## 6. HTSCS Applications

Here are a few significant HTSC applications. Because low temperature semiconductors are not as practical in this situation, it becomes crucial to employ high temperature semiconductors (HTSCs). A superconductor can always be made more easily at 122K than at 12K.

Magnetic Resonance Imaging (MRI) MRI is a non-intrusive medical imaging technique that creates a two-dimensional picture of say tumors and other abnormalities within the body or brain. MRI required a magnetic field to be set up for recording Images. Although normal electro-magnets can be used for this purpose, because of resistance they would dissipate a great deal of heat and have large power requirements. Supercon-ducting magnets on the other hand have almost no power requirements apart from operating the cooling. Once electrical current flows in the superconducting wire, the power supply can be switched off because the wires can be formed into a loop and the current will persist indefinitely as long as the temperature is kept below the transition temperature of the superconductor.

### 6.1. Imaging by Magnetic Resonancemri

Even while regular electromagnets may be used for this, their resistance would lead them to lose a lot of heat and consume a lot of power. On the other side, superconducting magnets use very little power—just enough to run the cooling. Because the wires may form a loop and the current will continue indefinitely as long as the temperature is maintained below the superconductor's transition temperature, the power source can be turned off after electrical current flows in the superconducting wire.

Magnetic Levitation Because of the diamagnetic nature of HTSCs, any magnetic field in contact with HTSC will get Magnetic Levitation Because of the diamagnetic nature of HTSCs, any magnetic field in contact with HTSC will get.

### 6.2. Electromagnetic Death

Any magnetic field that comes into contact with HTSCs will be rejected due to their diamagnetic nature. This phenomenon has the potential to be exploited to create levitation-based vehicles as an alternative to motor-driven ones, which are a very inefficient form of propulsion. These trains, sometimes known as Ma-lev trains, have previously been created. Even though they haven't been produced for commercial use, people have demonstrated that these trains are feasible and have a great deal of potential for the future. Maglev trains, for example, are known for their high efficiency because there are no friction losses and the train never touches the track.

### 6.3. Transformers

HTS transformers have been making the transition from laboratory to industrial settings because to advancements in high temperature superconductor (HTS). Fig. displays a prototype HTS transformer, which is a single-phase, 2 MVA (66kV/6.9kV) that was produced, tested, and assessed in 2005.

Transformers with the improvement of high temperature superconductor (HTS), HTS transformers have been moving from the laboratory stage to industrial applications. A single-phase 2 MVA (66kV/6.9kV) prototype HTS transformer has been manufactured, tested and evaluated in 2005 is shown in Fig Transformers With the improvement of high temperature superconductor (HTS), HTS transformers have been moving from the laboratory stage to industrial applications. A single-phase 2 MVA (66kV/6.9kV) prototype HTS transformer has been manufactured, tested and evaluated in 2005 is shown in Fig 4

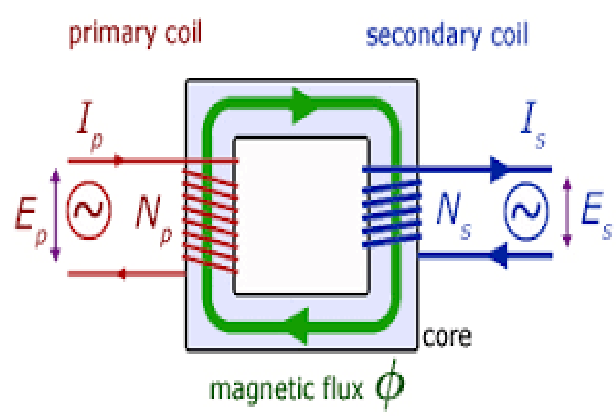


Figure 4: - HTS power transformer Source

The major attraction for HTS Transformer lies in the potential for reduction (compared to conventional) in losses, volume, and weight. Furthermore, it offers overloadability without accelerated aging and possible integration of a fault current limitation function. The main draw of HTS Transformer is its ability to reduce losses, volume, and weight in comparison to traditional methods. Moreover, overloadability is provided without hastening aging, and the inclusion of a fault current restriction mechanism is conceivable.

### 6.4. Motors

Over the last few decades, HTS wire development has advanced quickly, leading to the creation of HTS electromagnets that can function at far greater temperatures than those built of low temperature semiconductor materials. This presents benefit of cryogenic systems' relative simplicity, lower cost, and increased efficiency. Due to these advantages over LTS wires, HTS wires may now be commercialized for motor and generator applications at much lower power ratings both technically and financially.
The past few decades have seen a rapid advancement in the development of HTS wire, leading to the creation of HTS electromagnets that can function at significantly higher temperatures than those composed of low temperature semiconductor materials. This has the advantage of allowing for the creation of cryogenic systems that are more straightforward, affordable, and efficient. Because of these advantages over LTS, HTS wires are commercially feasible for motor and generator applications, allowing for far lower power ratings.

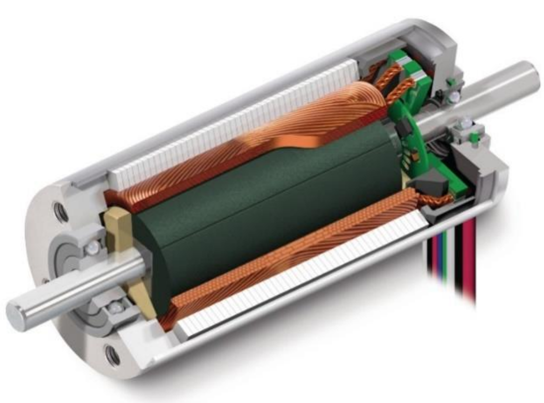

Figure 5: The 200 kW HTS motor's rotors with HTS coils in general perspective

For HTS motors, the synchronous machine is the preferred option. The majority of HTS machines use a traditional copper winding on the stator and a superconducting field winding on the rotor. An HTS motor and an HTS transformer have comparable potential advantages. great power density, great efficiency, and low noise output are offered by HTS motors.
The synchronous machine is the favorite choice for HTS motors. Most HTS machine employs superconducting field winding on the rotor, and a conventional copper winding on the stator. The potential benefits of an HTS motor are similar to that of HTS transformer. HTS motors provide high power density; high efficiency and low noise production ault Current Limiters There are fair odds of short circuits in the power system and appliances. A large current flows during a short circuit and causes power loss and may damage appliances as well. Superconducting fault current limiters (SCFCL) remain in superconducting state and offers no resistance during the normal state of operation, and in the event of a fault, it reverts to normal state and reduces the current passively. Superconducting Fault Current Limiters (SCFCL) (see Fig. 8) could enable the novel design of electric grids. Most HTS FCL concepts exploit the sharp transition of superconductors from zero resistance, at normal currents, to finite resistance at higher current densities.

### 6.5 Improve able Current Limits

The likelihood of short circuits in the appliances and electrical supply is rather high. During a short circuit, a significant current flow results in power loss and the potential destruction of equipment. During normal operation, superconducting fault current limiters (SCFCL) stay in a superconducting state and provide no resistance. In the case of a fault, however, they revert to a normal state and passively lower the current. Superconducting Fault Current Limiters (SCFCL) may make it possible to create innovative electric grid designs. The shift of superconductors from zero resistance at normal currents to finite resistance at higher current densities is a sharp feature that is used by most HTS FCL approaches.

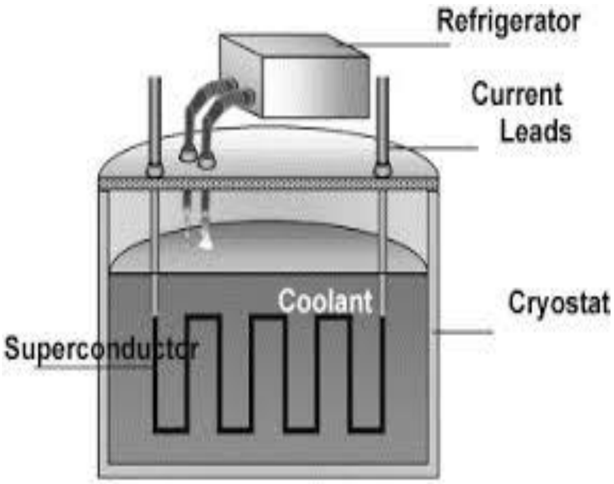


Figure 6: Superconducting fault current limiter with a closed cooling cycle is shown in.

In the case of a fault current, SCFCL passively executes instantaneous limiting. In normal operation, SCFCL has very little resistance. It is highly suitable for grids with large potential fault currents and makes an excellent fault current limiter. Various materials, such as YBCO films, Bi2223 wires, or Bi2212 bulk, are being developed as high temperature superconductors (HTS) for use in SCFCL. Designing grids with reduced impedance and better power quality is feasible using SCFCL.

With the improvement of high temperature superconductor (HTS), HTS transformers have been moving from the laboratory stage to industrial applications. A single-phase 2 MVA (66kV/6.9kV) prototype HTS transformer has been manufactured, tested and evaluated in 2005 is shown in Fig. 2019 The major attraction for HTS Transformer lies in the potential for reduction (compared to conventional) in losses, volume, and weight. Furthermore, it offers overloadability without accelerated aging and possible integration of a fault current limitation function.

The major attraction for HTS Transformer lies in the potential for reduction (compared to conventional) in losses, volume, and weight. Furthermore, it offers overloadability without accelerated aging and possible integration of a fault current limitation functional. High temperature semiconductors have already developed to the point that many commercial applications are in place.

With the bleeding edge of research, we are delving deeper into High Temperature superconductivity and trying to understand its cause. The mystery behind the formation of electron pairs will definitely fetches a Nobel Prize. Room temperature superconductors with desired materials will allow us to commercialize scientific prototypes and open new avenues.

## 7. Conclusion

Many different commercial applications have already been made possible by the development of high temperature semiconductors. We are delving further into High Temperature superconductivity and using state-of-the-art research to try to understand its genesis. The mystery of how electron pairs are created will surely earn a Nobel Prize. With room temperature superconductors composed of selected materials, we will be able to commercialize scientific prototypes and pave new directions. Review papers will be released in the future on a few of them, such as superconductive electronics. We may anticipate that NIST staff members will continue to make important new contributions to this exciting field given the attention that the new high-temperature superconductors and their potential economic ramifications are getting on an international level.

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