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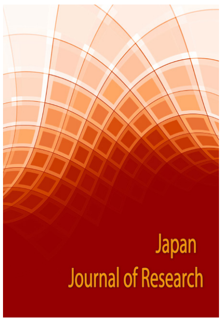

Superconductor Exclusion Principle for Identifying a Room Temperature Ambient Pressure Superconductor

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Abstract

A simple method, based on the Meissner effect, is suggested for identifying a possible room-temperature ambient-pressure superconductor with 100% certainty, which may be called the "Superconductor Exclusion Principle". In July 2023, LK-99 was claimed to be a room-temperature ambient-pressure superconductor, and it produced huge interest around the world, because of its potential applications in many industry sectors. However, it is difficult to produce pure samples for zero-resistance measurement. We point out that a neodymium magnet can exhibit superconductivity because of the Meissner effect, that is, diamagnetism, levitation, and quantum locking (levitation below a magnet), even for tiny samples. Nevertheless, this approach has never been systematically pursued. We stress that accurate Tc measurement is possible from quantum locking. The suggested Superconductor Exclusion Principle is, "if any proposed material does not show diamagnetism, levitation, and quantum locking in one sample, the material is not a superconductor." Note that CES-2023, discovered by Cutting Edge Superconductors on September 28, 2023, is a room temperature ambient pressure superconductor of Tc approximately 104° C = 377 K, according to this Superconductor Exclusion Principle.

Introduction

In July 2023, a Korean company, Quantum Energy Research Center claimed that LK-99, copper doped lead apatite, with the chemical formula, $Pb_{10-x}Cu_x(PO_4)_6O$, with $0.9 < x < 1.1$, is a room temperature ambient pressure superconductor [1,2]. It was sensational around the world, because of its potential applications in many industries, including electric power transmission and distribution, electric appliances, electric vehicles, computers, and smart phones. However, other scientists have shown that LK-99 is not a superconductor, but a ferromagnetic insulator [3,4].

Nevertheless, the Korean company obtained very small critical currents from some samples of LK-99 [1,2]. Cutting Edge Superconductors (CES) noticed that this result may be due to the presence of superconducting pieces in some LK-99 samples. In fact, the Korean company proposed that the superconducting quantum well produced results [1]. Note that Kopelevich et al. [5], reported a similar room-temperature superconductivity, with very small critical currents, in cleaved highly oriented pyrolytic Graphite on December 31, 2023.

CES produced many LK-99 samples, using the pellet technique and powder-in-tube technique, according to the recipe of the Korean company [1, 2], that is, sintering $Pb_2(SO_4)O$ and Cu_3P at 925° C for 5-20 h. For analysis, we broke the samples to identify potential superconducting pieces. Fortunately, on September 28, 2023, several small superconducting pieces were fabricated. The diamagnetic behavior video of our sample was posted on linkedin [6]. Quantum locking video, that is, levitating below a 180-degree tilted magnet, was also posted on linkedin [7]. We named this new material CES-2023, and this material is patent-pending.

Superconductors exhibit two characteristics: zero electrical resistance and diamagnetism, which is called the Meissner effect. The Meissner effect leads to quantum locking below a 180-degree tilted magnet. We stress that diamagnetism, levitation, and quantum locking together in one sample provide 100% proof of superconductivity. Only superconductors show diamagnetism, levitation, and quantum locking, whereas typical diamagnets show levitation and diamagnetism and cannot show quantum locking, below a 180-degree tilted magnet.

Note that resistance measurement usually requires samples with a size of at least 10mm. For samples much smaller than 10mm, the Meissner effect, that is., diamagnetism, levitation, and quantum locking in a small

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sample, is the simplest proof of superconductivity. LK-99 is difficult to prepare good quality samples with sizes greater than 10mm, including our CES-2023. Therefore, it is desirable to have a simple method or criterion for proving superconductivity in a very small sample for a possible room-temperature ambient-pressure superconductor. This approach, which is based on the Meissner effect, has not been fully explored.

We suggest the following "Superconductor Exclusion Principle" for identifying room-temperature ambient-pressure superconductors:

"If any proposed material does not show diamagnetism, levitation, and quantum locking in one sample, the material is not a room temperature ambient pressure superconductor."

Method

For samples less than 10mm in size, it is not easy to measure the electrical resistance using the usual 4-point contact technique. There is a more sophisticated technique for tiny samples using four micromanipulated probes in device-physics research [8, 9].

We can use a neodymium magnet to prove whether any proposed material is a room-temperature ambient-pressure superconductor with 100% certainty. This method is based on the Meissner effect of superconductors [10].

Meissner effect of superconductivity: diamagnetism, levitation, and quantum Locking

In 1933, Meissner and Ochsenfeld [11], found that superconductors expel magnetic fields and show perfect diamagnetism, which is called the Meissner effect. Perfect diamagnetism is due to the screening supercurrents that oppose the applied magnetic fields, as described by the London equation [12,13]. When a superconductor is over a magnet, it induces an opposite magnetic polarity to levitate on top of the magnet. We stress that the superconductor is in the equilibrium minimum energy state to demonstrate the Meissner effect. When a superconductor is rotated 90 ° or 180 ° with a magnet, the superconductor will still show levitation against gravity, which is called quantum locking. This quantum locking is due to the distortion of magnetic field, and the superconductor is trapped in the distorted magnetic field region, which is called flux pinning.

Note that the transition temperature can be accurately measured using quantum locking. For instance, a superconductor levitating near a 90-degree tiled magnet will fall at the transition temperature as the superconductor and magnet are heated inside the vacuum tube furnace. This technique can be a cheap and easy alternative to the usual Tc measurement based on the temperature dependence of the resistance or magnetization measurement.

Figure 1 shows the diamagnetic repulsion of a superconductor near a magnet in a horizontal plane, owing to the Meissner effect. Figure 2 shows the diamagnetic levitation of a superconductor against gravity. Note that high-Tc superconductors, including room-temperature ambient-pressure superconductors are type II superconductors. Figure 3 shows the quantum locking of a superconductor near a 90-degree tilted magnet. The Meissner effect produces flux pinning, leading to an upward lifting force against gravity, which is known as quantum locking.

Quantum locking disappears above the transition temperature. As a result, we can determine Tc accurately from the quantum locking of a superconductor while increasing the temperature of the superconductor by heating. The Tc of a superconductor

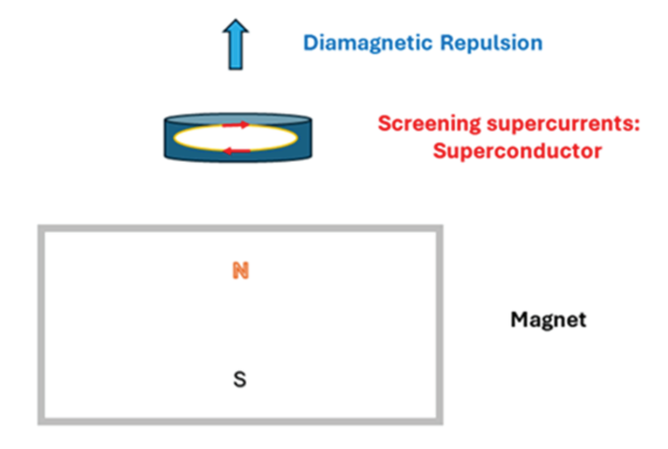


Figure 1. Diamagnetic repulsion of a superconductor near a magnet in a horizontal plane.

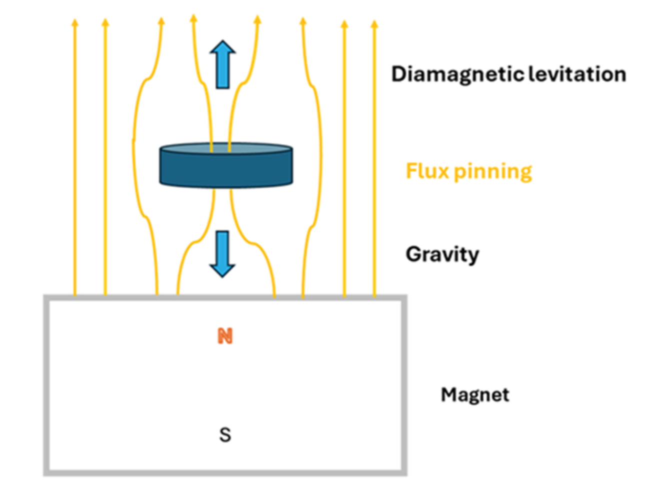


Figure 2. Levitation of a type II superconductor over a magnet. Note the flux pinning through the superconductor. So, the superconductor is pinned in the region where magnetic fields are distorted.

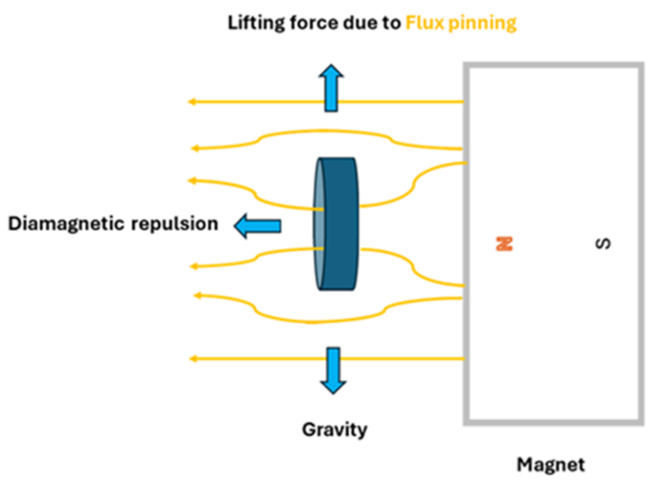


Figure 3. Quantum locking of a superconductor near a 90-degree tilted magnet. Note that the lifting force is due to the flux pinning.

is usually determined from the temperature dependence of the resistance or DC magnetization measurement which requires professional equipment. Note that quantum locking through a neodymium magnet can provide accurate Tc measurement, which is a simple and easy alternative to the above sophisticated techniques.

Diamagnet vs Superconductor

Diamagnets, such as Pyrolytic graphite, exhibit levitation due to diamagnetism. However, they show much weaker diamagnetism and no quantum locking, compared to superconductors. It should be noted that there is no flux pinning, unlike in superconductors. As a result, the diamagnet fell to the ground near a 90-degree tilted magnet.

Anisotropic polycrystalline ferrimagnet and/or mixed magnetism vs Superconductor

Ferrimagnets, such as magnetite Fe3O4, exhibit both ferromagnetic and anti-ferromagnetic ordering [15]. As a result, polycrystalline ferrimagnets consist of random N and S poles inside the material. When the LK-99 levitation video was released, some scientists suggested that the partial levitation may be due to mixed magnetism or anisotropic polycrystalline ferrimagnetic material [3, 4]. We stress that when a magnet approaches a mixed magnetic material or anisotropic polycrystalline ferrimagnetic material, the dominant N or S pole will dominate, that is, the material will be attached to the magnet quickly.

Results

We used a solid-state reaction to prepare LK-99, Pb9Cu(PO4)6O, according to the recipe of the Korean company [1, 2]:

Pb2(SO4)O + Cu3P → Pb10-xCux(PO4)6O + S (g),

where $0.9 < x < 1.1$.

All the powders, lead(II) oxide (PbO), lead(II) sulfate (Pb(SO4)), Cu, and P, were purchased from Sigma Aldrich. The produced LK-99 sample shows ferromagnetic behavior with reasonable metallic conductivity, as shown in Figure 4. The resistance is 2.65 Ω, and the resistivity was estimated to be $\rho=1.77 \times 10^{-1}$ Ω cm. Figure 5 shows the XRD data of our LK-99 sample (b) and the Korean company's LK-99 sample (a) [1, 2]. The measurement was performed in the Material Science and Engineering Department at the University of Puerto Rico,

Figure 4. *LK-99 sample made by solid-state reaction, according to the recipe from the Korean company [1,2]. Note that it shows the ferromagnetic attraction to the magnet and metallic behavior with resistance 2.65 ohm.*

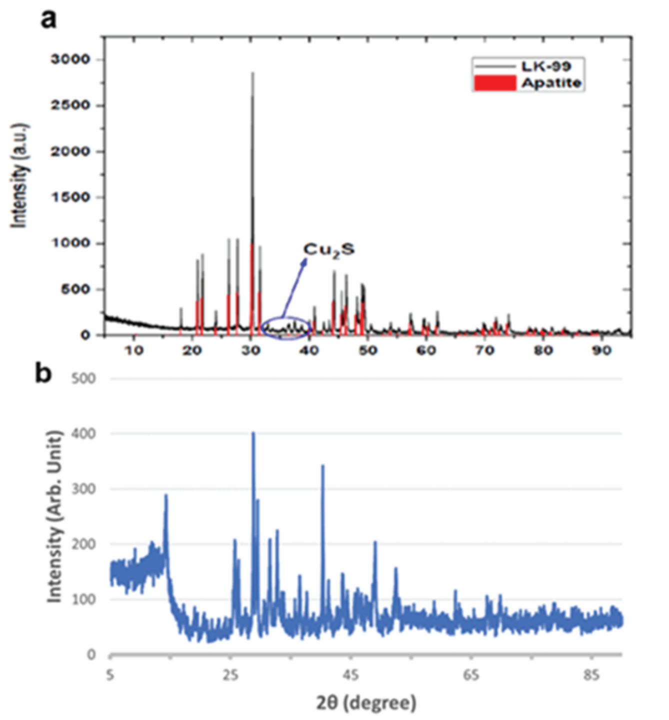


Figure 5. *XRD data comparison of our LK-99 sample (b) and the Korean company's sample (a) [1, 2]. Note the same main peaks between 25 and 32 degrees. LK-99 sample is inhomogeneous with impurity phases like Cu2S.*

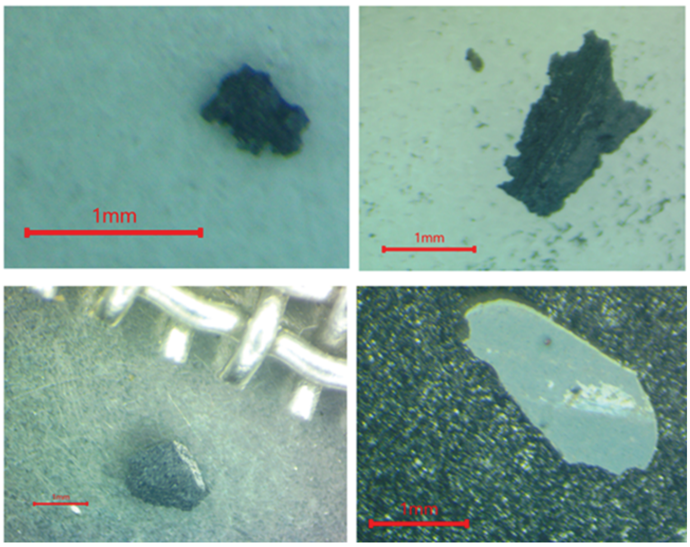


Figure 6. *Superconducting samples of CES-2023. The sample color is black or dark brown, except the last gray one.*

Mayaguez campus. The same main peaks were observed from 25° to 32°. Note that LK-99 is an inhomogeneous sample with several impurity phases, including Cu2S, as shown also in our LK-99 sample (b). Our XRD pattern of LK-99 (b) shows that there may be a CuS Covellite phase [16] and a Cu31S16 Djurleite phase [17]. A more detailed study is underway and will be reported elsewhere.

We modified the manufacturing recipe of the Korean company's LK-99 to induce diamagnetism and superconductivity. We added some catalysts during the solid-state reaction from our long-term

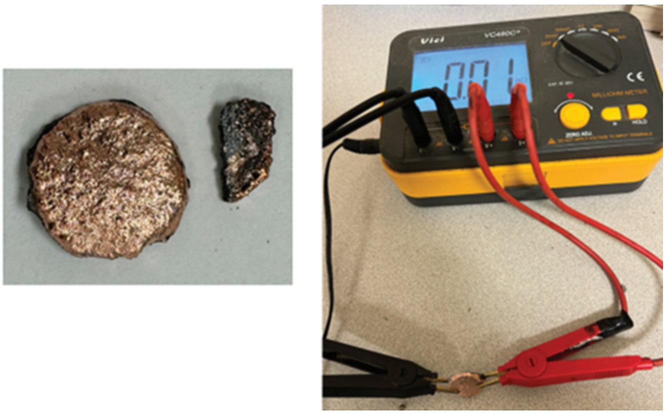


Figure 7. *Copper rich sample made by 15mm pellet die. It doesn't show the Meissner effect, whereas it has very low resistance, 0.00001 Ω, comparable to that of copper.*

experience of sample manufacturing, such as MgB2, conductive polymeric materials with nanostructures, magnesium carbides, and ceramics, including SiC.

Figure 6 shows our superconducting sample, named CES-2023. Most samples were a few millimeters in length. The largest sample measured approximately 5mm X 5mm. The last sample is gray in color, and shows weak levitation above a magnet. Due to the small sample size, we did not measure the resistance. However, we confirmed room-temperature ambient-pressure superconductivity by the Meissner effect, that is, diamagnetism, levitation, and quantum locking. Some copper-rich samples show a very low resistance 0.00001 Ω, as shown in Figure 7, which is comparable to that of copper, whereas it does not show the Meissner effect, that is, it is not superconducting.

We reiterate the proposed "Superconductor Exclusion Principle": "If any proposed material does not show diamagnetism, levitation, and quantum locking in one sample, the material is not a superconductor."

Meissner effect of superconductivity: Diamagnetism

Figure 8 shows the diamagnetic repulsion of the CES-2023 sample from the magnet. The video was uploaded to linkedin [18] and reddit [19], on September 28, 2023. The gif file for the diamagnetic repulsion is in supplementary material.

Note that unlike ferromagnets, there are no fixed N and S poles. We stress that as the magnet approaches the CES-2023 sample, the Meissner effect induces the screening supercurrents inside the superconductor sample to exclude the magnetic field of the magnet and repel the magnet. The magnet had better approach the superconductor sample slowly to minimize the eddy current due to the electromagnetic induction.

Meissner effect of superconductivity: Quantum locking

Figure 9 shows the quantum locking of the sample shown in Figure 8. The video was posted on linkedin [20], and reddit [21], on September 28, 2023. The gif file for the quantum locking is in the supplementary file, as the magnet is rotated 180 degrees. Note that the sample repels the magnet and shows diamagnetism. However, once the sample is on the magnet, it levitates and produces flux pinning owing to the screening supercurrents, leading to quantum locking, even though the magnet is rotating up to 180 °. The video for both quantum locking and diamagnetic repulsion of this sample was posted on TikTok [22]. Notice that more than 4,300 people liked the

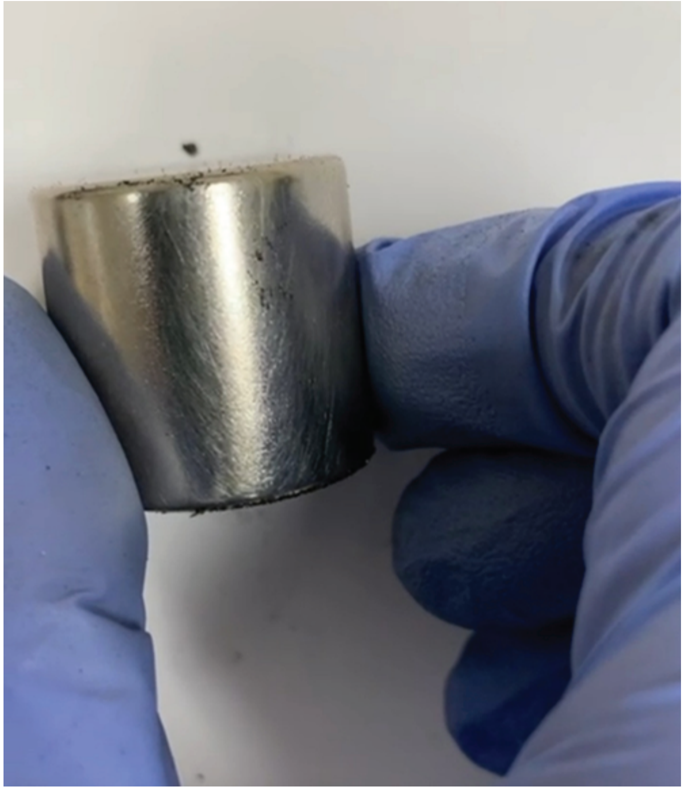


Figure 8. *Diamagnetic repulsion of a CES-2023 sample from a magnet. The gif file for the diamagnetic repulsion can be found in supplementary material.*

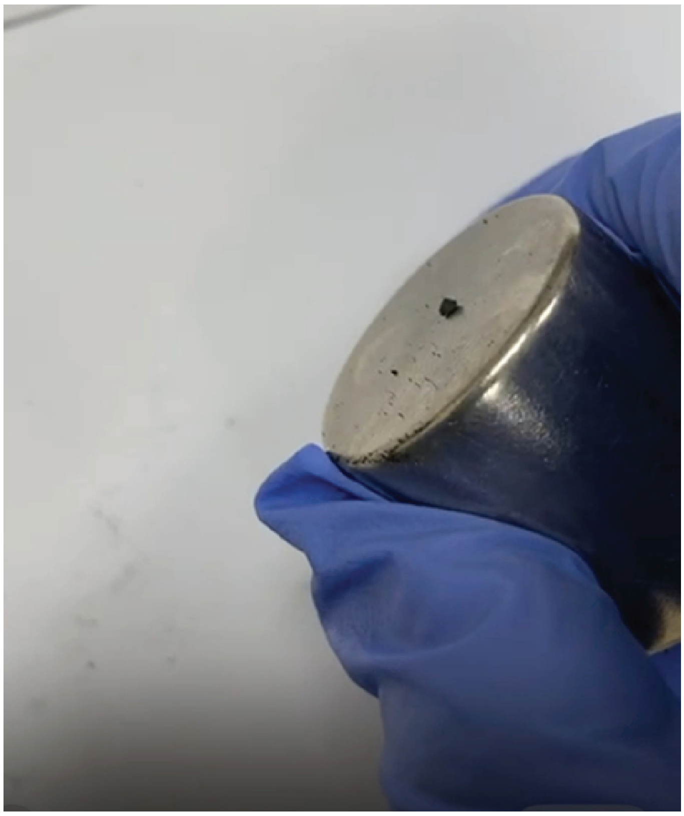


Figure 9. *Quantum locking of the same sample as Figure 8. Note that the superconductor, CES-2023 is not falling, due to the flux pinning. As the magnet is rotated 180 degrees, the quantum locking gif file is in the supplementary file.*

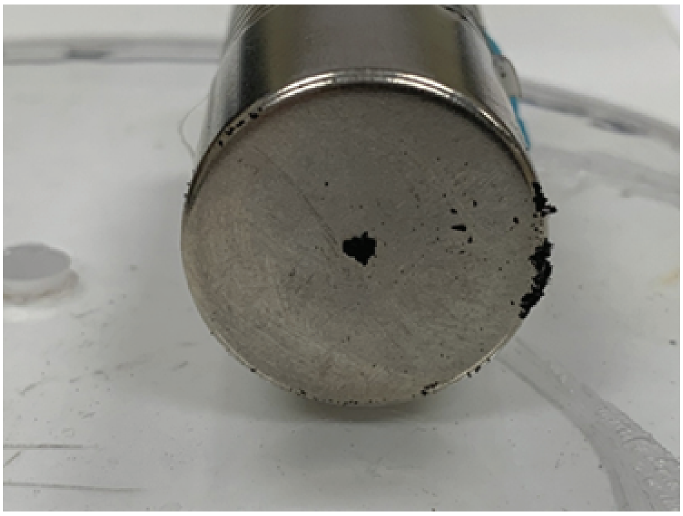


Figure 10. *Quantum locking of our sample near a 90-degree titled 1 inch magnet more than 2 months. Note that zero resistance supercurrents are flowing inside the sample more than 2 months continuously.*

video. Figure 10 shows the quantum locking of our CES-2023 sample near a 90 ° titled 1 inch magnet for more than 2 months, that is, zero-resistance supercurrents are flowing continuously inside the sample for more than 2 months.

Meissner effect of superconductivity: Levitation

Figure 11 shows the levitation of thin film-type sample of Figure 10. Good levitation is observed, although one side is still very close to the magnet surface. The levitation video was posted on YouTube [24]. When the sample is pushed to the magnet, it does not repel from the magnet immediately, presumably because of the sample quality. There seems to be some metastable flux states of the room temperature ambient pressure superconductor. Once pressed again, it levitated well, as shown in Figure 11.

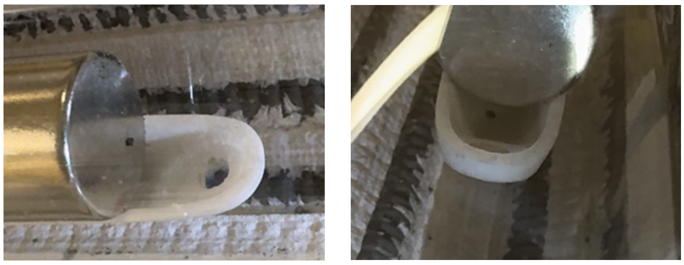
Tc measurement of CES-2023 from quantum locking

Quantum locking stops when the temperature exceeds the transition temperature Tc of any superconductor. As a result, we can determine the Tc of our CES-2023 based on the temperature dependence of the quantum locking. A vacuum tube furnace from Across International, STF 1200, was used to apply heat to the sample. Figure 12 shows that quantum locking occurred at 100 °C (a), whereas quantum locking stopped at 108 °C (b). So, the Tc is around 104 °C ± 3 °C = 377 K ± 3 K. A more accurate Tc measurement with a certainty 1 K will soon be performed. It was posted on YouTube [26]. The neodymium magnet with the chemical formula $Nd_2Fe_{14}B$, has the Curie temperature of 310 °C – 400 °C, [27]. So, the accurate Tc measurement by quantum locking around 100 °C is accurate enough. It is interesting that the Korean company claimed Tc = 105 °C for LK-99, based on the temperature dependence of the resistance [1,2].

Scanning Electron Microscopy (SEM) measurement of CES-2023

Scanning Electron Microscopy (SEM) measurement has been done for 100% pure small samples of CES-2023. SEM image shows the layered structure, as shown in Figure 13, indicating quasi-two-dimensional superconductivity, like high Tc cuprate superconductors, [29]. We think it may have infinite layers, which will be confirmed by TEM (Transmission Electron Microscopy) measurement soon. It seems that superconductivity occurs in 2-dimensional planes and the planes are coupled by the intrinsic Josephson effect. EDS (Energy-dispersive X-ray Spectroscopy) measurement results of CES-2023 will be also reported soon. Note that LK-99 assumes quasi-one-dimensional superconductivity [1, 2, and 27]..

Figure 11. *Levitation of CES-2023 on a magnet.*



(a) (b)

Figure 12. *Quantum locking of CES-2023 at 100° C (a) and no quantum locking at 108° C (b).*

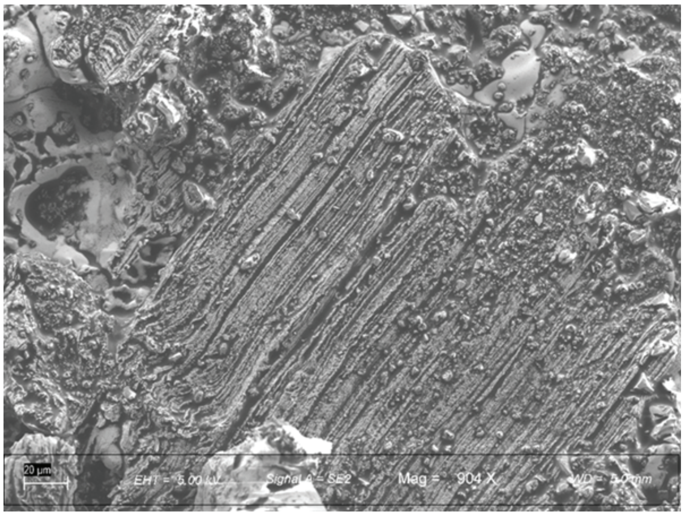


Figure 13. *SEM image of 100% pure small sample of CES-2023. Note the layered structure, like the high Tc cuprates, but unlike LK-99.*

Preliminary resistance measurement and magnetization measurement

Preliminary resistance measurement of impure samples, with less than 5% superconducting part shows the resistance drop around 104° C = 377 K [30, 31], in agreement with the quantum locking result in section 3.4. DC magnetization measurement by VSM (Vibrating Sample Magnetometer) also shows the weak superconducting diamagnetic behavior, when the background paramagnetic contribution is subtracted [32,33]. More thorough resistance measurement and magnetization measurement will be done soon.

Discussion

It is interesting that this Superconductor Exclusion Principle, employing a neodymium magnet, has not been systematically applied to many proposed superconducting materials, although this method is simple and easy to apply, especially to determine Tc, with good accuracy. The scientific community may be keener on professional techniques, rather than a simple method using a magnet.

We hope that this “Superconductor Exclusion Principle” based on the Meissner effect can facilitate the discovery of new superconductors, especially for small samples, at an early stage of discovery. This new method can complement zero-resistance measurement and DC magnetization measurement to prove superconductivity.

Conclusion

The Superconductor Exclusion Principle was suggested and applied to a new material CES-2023, discovered by Cutting Edge Superconductor in September 2023. The superconductor exclusion principle confirms that CES-2023 is a room-temperature ambient-pressure superconductor with a Tc of approximately 104° C = 377 K. SEM measurement shows the quasi-two-dimensional superconductivity, like high Tc cuprate superconductors. Its superconductivity seems to occur in 2 dimensional planes and the planes are coupled by intrinsic Josephson effect.

Declarations

Conflicts of Interest

The author declares that there is no conflict of interest.

Acknowledgement

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Supplemental Material

1. *Gif file for diamagnetic repulsion of CES-2023 from a magnet*

Gif file for quantum locking of CES-2023, as a magnet is rotated 180 degrees