Room-Temperature Superconducting Electronics:

An Unconventional Vibration Energy Technology And Potential Implications To Daily Lives

Emmanuel F.C. Chimamkpam
Cambridge

ABSTRACT: Off-the-shelf room-temperature superconducting electronics are unavailable today because all superconductors that were discovered in the last century required cold temperature to work, and were made of scarce exotic materials that were often very expensive and difficult to process. These problems come now to an end with recent breakthrough in stable room-temperature superconductivity. As more similar breakthroughs await disclosures, this article gears up governments, businesses and general public for the dawning of super-electronics and their implications to our daily lives as a commercially-viable groundbreaking technology. Not only that recent and first-time stable breakthrough is vibration-induced and passed all superconductivity tests at room-temperature, it eliminated the century-old commercialization impediments by use of readily available, affordable and easily processed materials, components and techniques. These commercial attractiveness inform a practical expectation that new generation electronics including smart televisions, mobile phones, laptops and cameras will be of superconducting technologies 'within' next two decades. Room-temperature superconducting electrical appliances will self-generate and permanently self-sustain their own electricity without batteries, wireless and wired plug-ins. Cost of electricity for operating quantum computers will be cheap. Today's electricity consumption and billing methods will become obsolete.

I. Introduction

Electronics as we know to date have an inherent problem of resistance to electrical current flow. This is the reason for costly power consumptions. Imagine how much could be saved annually in billions of dollars for electricity use in the United States of America if there is no electrical resistance? Superconductivity is all about the absence of electrical resistance in electricity, and when this absence is at room temperature (20–27 °C) it is then called room-temperature superconductivity.

For over hundred years now, necessity for cooling down superconductors with liquid Helium or liquid Nitrogen, in addition to high material costs, lack of market interests and reliability issues made it difficult to commercialize inventions for consumer applications. These cold superconductors were not completely a waste as they found evolving success in powerful cold electromagnets that are used today in the expensive medical magnetic resonance imaging (MRI) systems, in high energy physics experiments, and in demonstrations of train levitation. With just a few niche industries in the business, their impacts on our daily lives have not been felt and there has not been any urgency for a radical change in government and business policies and regulations governing supply, distribution and use of electricity.

The last six years witnessed fresh efforts and out-of-the-box thinking that involved different unusual approaches in search of room-temperature superconductors. These resulted in first-time breakthroughs, which were all possible through applying vibration as well as using vibration-responsive materials that produce electricity. While a first recorded breakthrough was too unstable and technically expensive for commercial applications, the latest and recent breakthrough is stable, passed superconductivity tests at room temperature, and has ended commercialization obstacles by use of readily available, inexpensive and easy to process materials and techniques. This is a new chapter in our age, where impossibilities become possibilities. What we must understand is that room-temperature superconductivity is a disruptive technology that will render every electronics able to generate and supply itself electricity without batteries, wireless and wired plug-ins. It will self-deregulate energy and power sectors of every economy, and inherently will disrupt the means and capabilities to price and bill electricity consumption. All aspects of our lives will be touched as everything around us is electronics. A cause to call on governments, industries and businesses for an immediate start in preparations for radical changes in policies, regulations and end-user agreements on supply, distribution and consumption of electricity. Pertinent to note that presently expensive applications that run on cold temperature superconductors will be inexpensive and accessible en masse with room-temperature superconducting technologies, and examples of these applications are in high energy Physics (e.g. electromagnets in particle accelerators and tokamaks), medicine (e.g. magnetic resonance imaging) and transportation (e.g. levitating electric trains).

This article will first present the background of superconductivity with its challenges that hindered its achievement at room-temperature since first discovery more than a century ago. This is followed by detailing the breakthroughs in room-temperature superconductivity, shedding light on the role of vibration and then will demonstrate the commercial viability. Pathways to discover and improve more room-temperature superconductors are offered. This will conclude by spelling out the potential impacts of room-temperature superconducting electronics on our daily lives and the necessity for early engagement on new policies and regulations among stakeholders including governments, businesses and general public.

II. Background - Over a Century of Cold Superconductivity

What is really known about the origin of superconductors has been from the works of Heike K. Onnes in 1911 when he observed the disappearance of electrical resistance in solid mercury at -268.95 degrees Celsius (4.2 Kelvin) [1], [2]. This temperature at which the superconductivity appears or electrical resistance disappears is what eventually became known today by Physicists as 'superconducting critical temperature (Tc)'. A further discovery by same inventor was made on permanent current flow in a superconducting coil after removal of power source [3]. This will be of immense importance in emerging applications of room-temperature superconductivity. In 1933, W. Meissner and R. Ochsenfeld discovered a scenario, known to this day as Meissner effect, where applied magnetic fields are expelled by superconductors [4]. Meissner effect became established as one of the 'Litmus tests' for validation of superconductivity discovery. Expelling of applied magnetic field is automatic in superconductors whereas same scenario only occurs in normal electrical conductors when an induced electric current becomes too large that it creates for itself a magnetic field that opposes an applied magnetic field.

With so many other discoveries to date, financed by governments, industries and philanthropists, it is greatly disappointing that everyday consumer applications are still non-existent. One main reason still floated is that most of these superconductors show their critical temperatures below boiling point of nitrogen at -196.15 degrees Celsius (77 Kelvin). However, the 1987 discovery of Yttrium Barium Copper Oxide (YBCO), a ceramic with wide range of technical applications, by Maw-Kuen Wu, Paul Chu (also known as Ching-Wu) and their co-workers would have changed the situation as the superconductivity of YBCO appears and disappears at -180.15 degrees Celsius (93 Kelvin) [5]. This transition temperature only offered the benefit that for the first time, cooling a superconductor down to its critical temperature would not require using liquid Helium since the 'cheaper to produce' and 'easier to handle' liquid Nitrogen could be used instead. Even so, after more than three-decades popularity of YBCO, it is unsatisfactory that there are no off-the-shelf household superconducting electronics. Commercially though, general consumers would not welcome to store liquid Nitrogen in their homes in order to watch their superconducting televisions even if with zero electricity bills.

III. Breakthroughs in Room-Temperature Superconductivity

In 2014, Kaiser and his co-researchers announced that YBCO can exhibit room-temperature superconductivity for a lifespan of few picoseconds when exposed to infrared laser pulses [6], [7]. This was the first known breakthrough in search for room-temperature superconductivity. However, the short lifespan made it highly unstable for any useful applications, and coupled with the need for a laser system it became unattractive for commercial developments.

Three years later in 2017, a patent application on room-temperature superconductivity was filed by S. C. Pais, which was assigned to the United States Navy [8]. This first stable superconductivity at room-temperature was achieved when electric current was passed through vibrating composite wire material made of an insulator core (e.g. Teflon) and a conductive coating (e.g. an aluminium metal coating or lead zirconate titanate (PZT) ceramic coating). The breakthrough satisfied all the three key conventional requirements for superconductivity, namely (a) must have zero electrical resistance, (b) must be perfectly diamagnetic (Meissner effect as described earlier in Section II), and (c) must have a macroscopic quantum coherence, described as the formation and condensation of electron pairs (Cooper pairs) into single quantum mechanical state. Since the superconducting wire was fabricated with already matured, cheap and readily available materials and processing techniques, it could easily be integrated into existing technologies and could be readily developed for new commercial applications.

IV. Vibration Creates Room-Temperature Superconductivity

The superconductivity of YBCO at room-temperature was explained by Kaiser and his co-workers to be a result of vibrating atoms that shifted away from their original crystal lattice positions which created a structural change (thicker copper dioxide double layers and thinner layer between them) that in turn increased the quantum coupling between double layers [6], [7]. The term 'melt' as an analogy to the transformation of solid to liquid has been used to explain such resulting outcome where, for example, an insulating or a poorly conducting material like a polymer becomes extraordinarily conductive if the atoms or molecules bound in the material are caused to vibrate, shift positions, and release avalanche of mobile charge carriers [9], [10], [11], [12]. If highly ordered fluid of paired electrons is formed in this process, then supercurrent with no electrical resistance is created. It is obviously easier to attain superconductivity at low temperature because of low entropy (better coherence) imposed naturally by cooling. Fluid of charge carriers including paired electrons is analogous to isolated water streams in a village, and superconductivity is registered if: (a) two supercurrent testers are in one isolated stream, (b) channels are established between streams (synchronizing isolated streams) such that two supercurrent testers are in different streams, or (c) material (~ village) is flooded entirely such that supercurrent testers are placed anywhere.

On this basis, materials ruled out as completely non-superconducting or just superconducting at very low temperatures could actually be superconducting and may even be room-temperature superconductors. This is supported by the case of YBCO, which was registered as superconducting at -180.15 degrees Celsius in 1987 and after nearly three decades was reported to be room-temperature superconducting in 2014. Vibration inducement is akin to flooding entire village or linking isolated streams. Applied vibration increases the movement of crystal lattice or chain backbones, releases new charge carriers and increases the mobility of all new and existing charge carriers. The more charge carriers a material structure can release, the most likely a stable continuous fluid of electric charges will be formed. Shifting of atomic and molecular positions, together with the release of charge carriers and their combination into pairs, will occur most at resonance. On applying vibrations at room-temperature, paired electrons from covalent bonds are likely to be set free in paired forms, with free electrons combining into new paired electrons. These are the possible origins of Cooper Pairs which can be sustained over wide range of temperatures. Short vibration duration will cause short-lived superconductivity as time is needed to release and build up stable low entropy Cooper Pairs. This is exemplified in the short lifespan of YBCO superconductivity caused by short laser pulse duration and small focus area of infrared irradiation. In contrast, electrical potential difference applied along PZT part of the PZT/Teflon composite wire excited large volume of the wire into longer time vibration duration by inherent stress-strain piezoelectric properties. Teflon, a high-resistance insulating polymer, is a large holding container of non-mobile charge carriers, both normal electrons and Cooper Pairs per se. When PZT/Teflon wire vibrates, charge carriers held by Teflon are released whereas PZT undergoes significant stress-strain intra-structural changes to induce intra-Teflon and inter-PZT/Teflon structural changes.

V. The Path To More Breakthroughs That Are Stable At Room-Temperature

For more discoveries and improvements to be made in room-temperature superconductivity, focus should primarily be on: (a) vibration responsive materials that produce electricity such as materials with inherent piezoelectric properties, and may include other inborn characteristics like pyroelectric and photoelectric effects; (b) combination of inorganic and polymer materials to form hybrids where piezoelectric materials constitutes the inorganic part, and where polymers should be poor vibration dampers as well as electrically conducting, even if having high resistivity but not insulating at room temperature and without doping agents in the polymer backbone; (c) ensuring chemical and mechanical stability of interfaces between polymers and piezoelectrics; (d) industrially processable polymers and piezoelectric materials using existing or modifiable techniques; (e) role of micro-nano-pico meter cracks, artificial air-gaps, or trapping wells designed into bulk and thin-film inorganic/polymer hybrid materials for inducing room-temperature superconductivity; (f) non-destructive vibration excitation sources with long duration for inducement of superconductivity.

For every discovery made in room-temperature superconductivity, high-resolution images from electron microscopes are required to shed light on general structure of interfaces. Studying grain boundaries through this technique will provide information on any limitations for critical current density and how to improve the materials. Deep studies with scanning tunnelling microscope and spectroscopy will be revealing in real time. Flatness of superconductivity behaviour across low and high temperature ranges, how wide or narrow these ranges are, and at what transition temperatures are technical information with high commercial interests that will drive further breakthroughs in room-temperature superconductivity.

VI. Commercial Viability of Breakthroughs

To be room-temperature superconducting is already a major market debut. However, other factors come into play for the big-picture commercial outlooks, incentives and benefits. How much will superconducting electrical components cost a manufacturer for a product? Is the cost worth it when compared to using conventional electronic components in manufacturing? What will be the immediate and long-term benefits of the final consumer product built from superconducting electronic components? What is the market size and value? These are factoring questions that are addressed with a deeper look on ways breakthroughs in room-temperature superconductivity are of commercial interests:

1. Superconducting at Room-Temperature

Superconductors that require cooling before operating are commercially unattractive. At the moment, YBCO under infrared irradiation has a very short lifespan at room temperature, and therefore is commercially unattractive. This has the potential to change in the future. In contrast, the recently discovered PZT/Teflon composite wire is commercially attractive because it does not require infrared laser excitation to be superconducting at room temperature. Moreover, PZT has high frequency-wide bandwidth response and can be tailored to be excited to any specific high resonance frequency at room-temperature [13], [14], which is commercially attractive for space technologies. Although little or no information is disclosed in the recent discovery about the chemical characterization, structural properties and measurement data, superconductivity at room temperature is important for hybrid superconductor/semiconductor components in our regularly used electronic systems. Information is not obvious about the critical current density, that is the amount of supercurrent that can pass through the composite wire when it is vibrating. However, the possibility to tune vibration characteristics of the PZT, including intensity and frequency-response [14], makes it possible to operate the superconductor at low or at high current, with commercial applications in industrial sensors and in areas like medicine where high-current capacity in high magnetic fields is needed.

2. Cost-Efficiency

Breakthroughs in room-temperature superconductivity eliminate the use of liquid Helium and liquid Nitrogen, and as a result reduce the costs of commercial developments, day-to-day consumer usage as well as maintenance. Large cost-saving from zero power losses is one of the general competitive advantages of superconductivity, whether room-temperature or not. In contrast to the exotic and scarce YBCO, PZT/Teflon composite superconducting wire already has advantage of low-cost for commercial applications as: (a) large volumes of research and manufacturing have been done with PZT and Teflon so it will be easy to find solutions for any problems during and after developments for any application. (b) industrial coating process and commercially attractive methods of making polymer-inorganic composites are well known and practically developed. (c) the process of making wires is cheap, and applications of wires are uncountable. Every conventional electronic wire will be replaced by room-temperature superconducting wire to save long-term cost of power losses due to conventional wire resistance. (d) PZT and Teflon materials are readily available, easier to handle and cheaper than YBCO.

3. Stability and Longevity

The long-term reliability of a superconducting material in real application is often a serious point of issue for commercial interests and viability. This is where technical characterizations of materials and technology come into play. How long will a superconducting wire last when is in use? Short lifespan technologies are commercially unattractive. Chemical, physical and micro-nano structural characterizations of a superconducting material are indispensable in determining stability and lifespan. From earlier researches and industrial utilities, PZT and Teflon have individually good chemical, thermal and mechanical stability. Reliability at room-temperature conditions may not be a burden for the superconducting properties of this composite materials. Nevertheless, the interface between the two materials will need deeper material characterizations. Cracks tend to originate faster at interfaces. Developments and improvements normally addresses different levels of reliability targeted to specific commercial applications.

4. Market Value and Demand

Room-temperature superconducting materials and technologies are revolutionary and disruptive with very high competitive stakes in market grabs. Imagine a global phase out and replacement of what we know today as resistant-laden electronics with affordable room-temperature power-lossless superconducting electronics? Electronics are well known as a high-turnover market, and for certain will provide so many multi-million dollar niches for new superconducting electronics and infrastructures, including capacitors, transformers, power storage devices, electric motors, spintronic devices, light-emitting diodes, smart grids for lossless electric power transmission, magnetic levitation devices, personal gadgets like laptops, mobile phones, cameras, and home electronics like smart televisions, refrigerators, cooking ovens, etc, all built entirely from superconducting components.

VII. Potential Impacts On Our Daily Lives

In this age of global connectivities, the evolutions, developments, advancements and adoptions of new technologies by the populace happen in the twinkle of an eye. With the doorway opened to breakthroughs in stable room-temperature superconductivity, it is not unimaginable to forecast that most electronics of today will become obsolete within next two decades and replaced by 'super-electronics' that are operating basically on superconductors. The potential impacts to our societies are innumerable.

For instance, power transmission lines for distribution of electricity will become lossless and save billions of revenues for governments. However this advantage, power transmissions will become less used anyway as superconducting electronics supplied to the market by industries will be self-powered - (a) based on century-old invention by Onnes on permanent current flow in a superconducting coil after removal of power source [3], and (b) vibrations will be serving as means to generate electricity within electronics and to concurrently induce superconductivity [13], [14]. That is to say that super-electronics will be shipped without wire plug-ins for wall sockets, and they will have no enclosures for battery usage, which will cut down on battery wastages and environment pollution. Electric cars, trucks, drones and all types of vehicles will operate without batteries, making them light-weight, more user- and eco-friendly without recharging needs. The rising trend in demand for dependence on today's alternative energy sources like solar and wind will gradually fall down.

With superconducting technologies and its inherent wireless nature becoming integrated in all mobile devices, internet will become a fully decentralized peer-to-peer network, eliminating communication blackouts by natural disasters and 'malevolent' users. High population density in major cities with its social problems and environment pollution will naturally drop down as superconducting technologies de-cluster the cities and enable quality rural living. Hand-held room-temperature superconducting 3D printers that are capable of printing electronics, ceramics, metals, polymers and foods will be a norm. Printable, foldable and recyclable shelters with all basic amenities including heating, cooling, cooking, water generation and home gadgets will become a reality.

Cost of accessing MRI in the hospitals for treatments will drop or become free by use of room-temperature superconductors in MRIs. Defibrillators and heart pacemakers will no longer require recharging or change in batteries. Modern organic farming for natural food production will become revolutionized as agricultural tools and equipment including robotized tractors go super-electric.

While overall GDP of nations will increase due to exponential increase in creativity, productivity and lifespan of the populace, it is clear that the economics of current utility billings and payment methods for electricity consumption will become obsolete over time as a consequence of revolution in room-temperature superconducting electronics.

If billing of electricity consumption shall continue, then its governing regulatory framework shall shift to become the responsibility of electronics manufacturing industries. Installation of smart metering devices may be imposed for utility bills on every superconducting electronics. However, compliance by industries will be technically and economically challenging. Socially, the general populace may likely revolt against such metering devices. Governments may resort to an increased taxation of superconducting technologies as most convenient means to replace obsolete utility billings. Again, the general populace and industries may likely revolt against such increased taxation. Summarily, this is a clarion call to governments, businesses, general public and all stakeholders to initiate plans and engage in early discussions, information sharing and consensus for overhauling of the policies and regulations on supply, distribution and consumption of electricity.

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