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Superconducting Parameters of Cuprates Due to Microwave Irradiation In The Framework Of The Variational Theory

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***Abstract*—Particle irradiation has been employed in high temperature superconductors to create flux pinning centres so as to enhance superconductivity, but with the danger of causing radioactivity in these materials. We employ theoretical technics in stimulating superconductivity in cuprates through microwave irradiation in the framework of the variational theory. Experimental research show that in cuprates, electrons that form Cooper pairs are as a result of d-wave transitions. In this research, a model is proposed in which the d wave transitions are stimulated through microwave irradiation. The cuprate is subjected to the microwave energy sufficient to give d transitions that form Cooper pairs. The results show that a minimum coherence length of 0.23 Å is required for a strong coupling at a microwave energy of $693.3\ \mathrm{eV}$. The results reveal the existence of two energy gaps, pairing energy gap of $0.13\mathrm{eV}$ on either side of the Fermi level and pseudogap above Tc beginning from $0.13\ \mathrm{eV}$. The minimum energy required for the onset of energy gap is $700\ \mathrm{eV}$.**

***Keywords*— High temperature, cuprates, d-wave, energy gap, coherence length, pseudogap.**

1. Introduction

First discovered in 1911**,** superconductivity is the ability of certain materials to exhibit zero d.c electrical resistance to the flow of current and expel magnetic fields from the core of the material when cooled below transition temperature Tc. This resistanceless state enables persistent currents to be established in the circuit to generate enormous magnetic fields and to store and transport energy without dissipation (Chowdhury, Rahman, Rahman, Bhuiyan, & Ali, 2016). In the quest to enhance formation of Cooper pairs, irradiation has been employed in high Tc superconductors to facilitate the transition of these materials into the superconducting phase. The particles so far employed in irradiation of High Tc superconductors are light elements such as Helium nucleus, protons, neutrons and ion beams. Each of these particles employed have been used to irradiate various systems causing diverse effects on the superconducting materials. These particles result in a shift in superconducting parameters hence enhancement of Superconductivity. Neutron and proton irradiation may lead to the formation of flux pinning centres which become sites for the penetration of magnetic fields which enhance superconductivity, although they may cause radioactivity which is undesirable for the stated system.

Among the classes of high Tc superconducting materials, cuprates have shown high prospects of superconducting at high temperatures and atmospheric pressure. Thus these materials are most probable for practical applications. The prevailing challenge in discussing cuprate based superconductors is the lack of understanding of the fundamental electronic correlation that leads to energy gap formation (Odhiambo, Sakwa, Rapando, & Ayodo, 2016). It is also important to note that high Tc superconductivity in cuprates take place predominantly in the Cu-O plane (Odhiambo & Makokha, 2018). In the Cu-O plane the apical oxygen plays a key role in the d-wave pairing that enhance superconductivity. Within the Cu-O plane oxygen ion contributes dominantly to the low frequency state which facilitate the d-wave pairing symmetry (Bussmann-Holder, Genzel, Bishop, & Simon , 1997). To enhance the Cooper pairing of the cuprates, electromagnetic energy in the microwave range is irradiated on the sample. These materials are of perovskite nature and able to absorb the microwave radiation (Ulloa, 2019). He remarks that the ability of cuprates to absorb microwave radiation is due to the presence of unpaired electron spins, fluxoids dynamics and quasiparticle motion. Irradiation of the cuprates within the required frequency range of the electromagnetic energy enhances transition into the coherent phase hence superconductivity is achieved. The highest value of Tc has been recorded in a non cuprate material Lanthanum decahydride (LaH_{10}) with a Tc value of 250K (-23^{0}C) at 200 GPa (Somayazulu, et al., 2019). As research in the area of superconductivity is being pursued, much interest is obtaining a material able to achieve room temperature superconductivity at room conditions of temperature and pressure.

The response of superconducting materials to electromagnetic radiation has been employed in diverse applications (Lara, Aliev, Silhanek, & Meshchalkov, 2015). These materials have been made useful in transport sector (levitated trains), satellite communication, particle accelerators, medical field (Nuclear Magnetic Resonance and Magnetic Resonance and Imaging equipment) and precision instruments such as the Superconducting Quantum Interference Device (SQUID). Although the very low temperatures used in the cooling of these materials have limited the practical applications of these materials.

The Hamiltonian for a many electron system in 3D is given as;

$$H = \frac{-\hbar^2}{2m}\frac{1}{r^2\sin\theta}\left[sin\theta\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right) + \frac{\partial}{\partial\theta}\left(sin\theta\frac{\partial}{\partial\theta}\right) + \frac{1}{\sin\theta}\frac{\partial^2}{\partial\phi^2}\right] + \frac{1}{2}kr^2 \qquad (1.0)$$

The potential term used in this Hamiltonian is the interaction of the cooper pair and the cuprate lattice which is exhibited as phonon interaction.

The d wave wavefunction for the $3d_{x^2-y^2}$ orbital was used.

$$\Psi_{3d_{x^2-y^2}} = \frac{1}{162\sqrt{\pi}a_0^{\frac{3}{2}}}\frac{r^2}{a_0^2}e^{-\frac{r}{3a_0}}e^{2i\phi}\, sin^2\theta \qquad (1.1)$$

A variational parameter α is introduced on the d wave wave function which is then subjected to the Hamiltonian in eq. 1.0 to give

$$E_d = \int\left\{\left(\frac{1}{162}\left(\frac{1}{a_0\pi}\right)^{\frac{1}{2}}\frac{1}{a_0^3}r^2e^{-\alpha\left(-\frac{r}{3a_0}+2i\phi\right)}sin^2\theta\right)\left[\frac{-\hbar^2}{2m}\left[\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\left(\frac{1}{162}\left(\frac{1}{a_0\pi}\right)^{\frac{1}{2}}\frac{1}{a_0^3}r^2e^{\alpha\left(-\frac{r}{3a_0}+2i\phi\right)}sin^2\theta\right)\right) + \frac{\partial}{\partial\theta}\left(sin\theta\frac{\partial}{\partial\theta}\left(\frac{1}{162}\left(\frac{1}{a_0\pi}\right)^{\frac{1}{2}}\frac{1}{a_0^3}r^2e^{\alpha\left(-\frac{r}{3a_0}+2i\phi\right)}\, sin^2\theta\right)\right) + \frac{1}{\sin\theta}\frac{\partial^2}{\partial\phi^2}\left(\frac{1}{162}\left(\frac{1}{a_0\pi}\right)^{\frac{1}{2}}\frac{1}{a_0^3}r^2e^{\alpha\left(-\frac{r}{3a_0}+2i\phi\right)}\, sin^2\theta\right)\right] + \left(\frac{1}{162}\left(\frac{1}{a_0\pi}\right)^{\frac{1}{2}}\frac{1}{a_0^3}r^2e^{\alpha\left(-\frac{r}{3a_0}+2i\phi\right)}\, sin^2\theta\right)\frac{1}{2}kr^2\left(\frac{1}{162}\left(\frac{1}{a_0\pi}\right)^{\frac{1}{2}}\frac{1}{a_0^3}r^2e^{\alpha\left(-\frac{r}{3a_0}+2i\phi\right)}\, sin^2\theta\right)\right]\right\}d\tau \qquad (1.2)$$

Eq. 1.2 is simplified to yield;

$$E_d = (3.810\times10^{-5})\frac{-\hbar^2}{2m}\frac{1}{\pi}\frac{1}{a_0{}^7}\int\left\{\left[\left(6r^2sin^4\theta - 2r^3sin^4\theta\frac{\alpha}{a_0} + \frac{\alpha^2}{9a_0{}^2}r^4sin^4\theta\right) + (4\,r^2\sin^2\theta\cos^2\theta - 2\,r^2\sin^4\theta) - 4\alpha^2r^2\sin^2\theta\right]\right\}d\tau + (3.810\times10^{-5})\frac{k}{2\pi}\frac{1}{a_0{}^7}\int\{\{r^6\ \sin^4\theta\}\}d\tau \qquad (1.3)$$

The volume element for spherical polar coordinates is given by;

$d\tau = r^2\sin\theta\, dr\, d\theta\, d\varphi$

Hence equation 1.3 become

I. D WAVE ENERGY

$$E_d = (3.810\times10^{-5})\frac{-\hbar^2}{2m}\frac{1}{\pi}\frac{1}{a_0{}^7}\int\left\{\left[\left(6r^4sin^5\theta - 2r^4sin^5\theta\frac{\alpha}{a_0} + \frac{\alpha^2}{9a_0{}^2}r^6sin^5\theta\right) + (4\,r^4\sin^3\theta\cos^2\theta - 2\,r^4\sin^5\theta) - 4\alpha^2r^4\sin^3\theta\right]\right\}dr\, d\theta\, d\varphi + (3.810\times10^{-5})\frac{k}{2\pi}\frac{1}{a_0{}^7}\int\{\{r^8\ \sin^5\theta\}\}dr\, d\theta\, d\varphi \qquad (1.4)$$

Integrating 1.4 without limits gives;

$$E_d = \left[(3.810\times10^{-5})\frac{-\hbar^2}{2m}\frac{1}{\pi}\frac{1}{a_0{}^7}\left[\left(\frac{6r^5}{5}\left(-\frac{1}{5}\sin^4\theta\cos\theta - \frac{4}{15}\sin^2\theta\cos\theta - \frac{8}{15}\cos\theta\right) - \frac{2}{5}\frac{\alpha}{a_0}r^5\left(-\frac{1}{5}\sin^4\theta\cos\theta - \frac{4}{15}\sin^2\theta\cos\theta - \frac{8}{15}\cos\theta\right) + \frac{4\alpha^2}{5}r^5\left(-\frac{1}{3}\sin^2\theta\cos\theta - \frac{4}{15}\sin^2\theta\cos\theta - \frac{8}{15}\cos\theta\right)\right) - \frac{4}{5}r^5\left(-\frac{1}{5}\sin^2\theta\cos^3\theta - \frac{2}{15}\cos^3\theta\right) - \frac{2}{5}r^5\left(-\frac{1}{5}\sin^4\theta\cos\theta - \frac{4}{15}\sin^2\theta\cos\theta - \frac{8}{15}\cos\theta\right) - \frac{4\alpha^2}{5}r^5\left(-\frac{1}{3}\sin^2\theta\cos\theta - \frac{2}{3}\cos\theta\right)\right]\varphi\right] + \left[(3.810\times10^{-5})\frac{k}{2\pi}\frac{1}{a_0{}^7}\left(-\frac{1}{45}\sin^4\theta\cos\theta - \frac{4}{135}\sin^2\theta\cos\theta - \frac{8}{225}\cos\theta\right)\right] \qquad (1.5)$$

We minimize the energy of the d-wave by equating its α derivative to zero.

$$\frac{dE_d}{d\alpha} = \left[\left(-\frac{2}{5}\frac{1}{a_0}r^5\left(-\frac{1}{5}\sin^4\theta\cos\theta - \frac{4}{15}\sin^2\theta\cos\theta - \frac{8}{15}\cos\theta\right) + \frac{8\alpha}{5}r^5\left(-\frac{1}{3}\sin^2\theta\cos\theta - \frac{4}{15}\sin^2\theta\cos\theta - \frac{8}{15}\cos\theta\right)\right) - \frac{8\alpha}{5}r^5\left(-\frac{1}{3}\sin^2\theta\cos\theta - \frac{2}{3}\cos\theta\right)\right] = 0 \qquad (1.6)$$

Hence, the variational parameter is obtained as;

$$\alpha = \frac{\left(\sin^2\theta + \frac{4}{3} + \frac{8}{15\sin^2\theta}\right)}{4\left(\frac{4}{3} + \frac{8}{15\sin^2\theta} + \frac{10}{3\sin^2\theta}\right)} \qquad (1.7)$$

Substituting eq.1.7 into eq.1.5 gives the minimum energy of the d wave as;

$$E_d = \Bigg[(3.810\times10^{-5})\frac{-\hbar^2}{2m}\frac{1}{\pi}\frac{1}{{a_0}^7}\Bigg[\Bigg(\frac{6r^5}{5}\left(-\frac{1}{5}\sin^4\theta\cos\theta - \frac{4}{15}\sin^2\theta\cos\theta - \frac{8}{15}\cos\theta\right) - \left[\frac{\left(\sin^2\theta+\frac{4}{3}+\frac{8}{15\sin^2\theta}\right)}{4\left(\frac{4}{3}+\frac{8}{15\sin^2\theta}+\frac{10}{3\sin^2\theta}\right)}\right]\frac{2}{5}\frac{1}{a_0}r^5\left(-\frac{1}{5}\sin^4\theta\cos\theta - \frac{4}{15}\sin^2\theta\cos\theta - \frac{8}{15}\cos\theta\right) + \left[\frac{\left(\sin^2\theta+\frac{4}{3}+\frac{8}{15\sin^2\theta}\right)}{4\left(\frac{4}{3}+\frac{8}{15\sin^2\theta}+\frac{10}{3\sin^2\theta}\right)}\right]^2\frac{4}{5}r^5\left(-\frac{1}{3}\sin^2\theta\cos\theta -$$

II. MICROWAVE ENERGY

The microwave wavefunction is given by;

$$\Psi_M = \frac{1}{(2\pi\hbar)^{\frac{1}{2}}}e^{-i(kr+\omega t)} \qquad (1.9)$$

A variational parameter $\boldsymbol{\alpha}$ that determines the frequency of the radiation is introduced in the microwave wavefunction which is then subjected to the Hamiltonian in eq. 1.0 to obtain the energy of the system as;

$$E_M = \int\left\{\frac{1}{(2\pi\hbar)^{\frac{1}{2}}}e^{-\alpha(kr+\omega t)}\left\{\frac{-\hbar^2}{2m}\frac{1}{r^2\sin\theta}\left[sin\theta\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right) + \frac{\partial}{\partial\theta}\left(sin\theta\frac{\partial}{\partial\theta}\right) + \frac{1}{\sin\theta}\frac{\partial^2}{\partial\phi^2}\right] + \frac{1}{2}kr^2\right\}\frac{1}{(2\pi\hbar)^{\frac{1}{2}}}e^{\alpha(kr+\omega t)}\right\}d\tau \qquad (1.20)$$

The derivatives with respect to θ and ϕ reduce to zero since the expression on which they act are independent of θ and φ respectively. Eq. 1.20 is simplified to;

$$E_M = \frac{-\hbar}{m}\left(\boldsymbol{\alpha}kr^2+\boldsymbol{\alpha}^2k^2\frac{r^3}{3}\right) + \frac{kr^5}{\hbar} \qquad (1.21)$$

To obtain variational parameter $\boldsymbol{\alpha}$ which minimizes the energy of the microwave, we calculate the derivative of E_M and equate to zero. The variational parameter is obtained as;

$$\boldsymbol{\alpha} = \frac{3}{2\,kr}. \qquad (1.22)$$

This expression of the variational parameter is substituted into the energy expression of the microwave wavefunction and simplified to give;

$$E_M = \frac{-\hbar}{m}\left(\frac{15}{4}r\right) + \frac{kr^5}{\hbar} \qquad (1.23)$$

For d-transitions to occur the ground state d-wave energy is assumed to be equal to the minimized microwave energy.

III. RESULTS AND DISCUSSIONS

The values of the constants below, befitting superconducting cuprates are used;

Radius r	$9a_0$
Electronic charge e	$1.6\times10^{-19}C$
Elastic Constant k	$2.2\times10^{7}GPa$
Mass of an electron m	9.11×10^{-31}
Bohr radius a_0	$0.529Å$

$$\frac{4}{15}\sin^2\theta\cos\theta - \frac{8}{15}\cos\theta\right)\Bigg) - \frac{4}{5}r^5\left(-\frac{1}{5}\sin^2\theta\cos^3\theta - \frac{2}{15}\cos^3\theta\right) - \frac{2}{5}r^5\left(-\frac{1}{5}\sin^4\theta\cos\theta - \frac{4}{15}\sin^2\theta\cos\theta - \frac{8}{15}\cos\theta\right) - \left[\frac{\left(\sin^2\theta+\frac{4}{3}+\frac{8}{15\sin^2\theta}\right)}{4\left(\frac{4}{3}+\frac{8}{15\sin^2\theta}+\frac{10}{3\sin^2\theta}\right)}\right]^2\frac{4}{5}r^5\left(-\frac{1}{3}\sin^2\theta\cos\theta - \frac{2}{3}\cos\theta\right)\Bigg]\varphi\Bigg] + \left[(3.810\times10^{-5})\frac{k}{2\pi}\frac{1}{{a_0}^7}\left(-\frac{1}{45}\sin^4\theta\cos\theta - \frac{4}{135}\sin^2\theta\cos\theta - \frac{8}{225}\cos\theta\right)\right] \qquad (1.8)$$

Boltzman constant K_B	$1.3807\times10^{-23}JK^{-1}$
Pie π	3.142
Planck's constant h	$6.626\times10^{-34}Js$
Reduced planck's constant $\hbar$	$1.054\times10^{-34}Js$

A. *Microwave energy and Coherence length.*

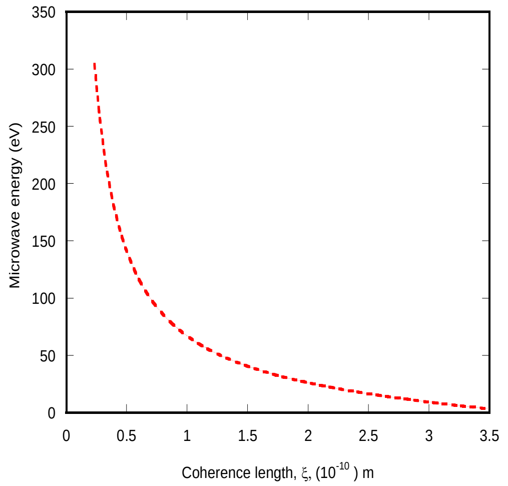

Fig 1: Graph of microwave energy and coherence length of superconducting cuprates.

Fig. 1 shows a non-linear reduction of microwave energy with increase in coherence length. We observe the smallest coherence length of $0.23Å$ at an electromagnetic energy of $300\,eV$. At lower electromagnetic energies large coherence lengths are obtained implying a weakly bound Cooper pair which cannot enhance superconductivity. For instance electromagnetic energy of $9.136\,eV$ corresponds to coherence length of 3.007 Å.

This value of coherence length is within the range of coherence length for cuprates. Below this energy much larger coherence lengths are obtained outside the cuprate range. A small coherence length imply strongly bound Cooper pairs (strong coupling) evidenced by the reduced coherence length that can sustain superconductivity against any destructing factors such as high temperature. Hence this is the most suitable regime for high Tc superconductivity. Low levels of electromagnetic wave on the cuprate increases coherence length leading to a weakly bound cooper pair which can break and destroy superconductivity. According to Andrei 2004, cuprates have a consistent coherence within a range of 1-3 Å. These results also seem to show consistency with Rapando (Rapando, 2013) who obtained a high value of Tc at coherence length below 3Å. Although the coherence length for high Tc superconducting cuprates lie within a range of 1-3Å the most probable coherence length is very small.

The size of a cooper pair in cuprates is small in the range of 1-3Å (Andrei, 2004). This results agree with the experimental results where LBCO with a coherence length of 7Å has a Tc value of 38K, YBCO with coherence length of 4Å has a Tc value of 94K and BSCCO with coherence length of 2Å has a Tc value of 110K (Koo & Cho, 2006). It is thus accurate to state that a short coherence length enhances superconductivity.

In their experimental study, Antonio Lara et.al observed increasing vortex radius with decreasing frequencies of the microwave radiation (Lara, Farkhad, Alejandro, & Victor , 2019). This experimental study show that with increased frequencies of microwave radiation, vortex radius would decrease. Vortex radius being approximately equal to coherence length would imply enhanced superconductivity with reduced coherence length.

B. Microwave energy and superconducting energy gap

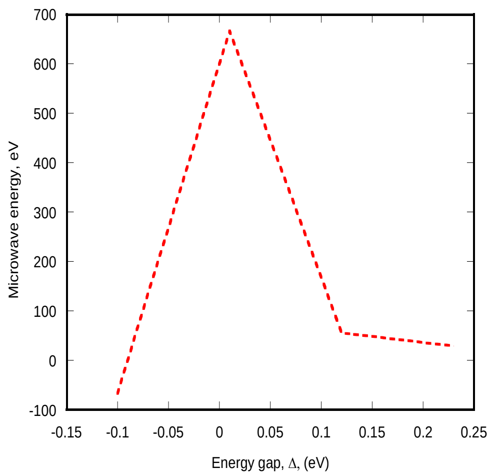

Fig 2: Graph of variation of microwave energy and energy gap

Variation of the microwave energy and superconducting energy gap is given from equation 1.5. Superconducting energy gap an important feature in the high Tc superconducting cuprates varies linearly with the microwave energy.

The attractive interaction between two electrons stimulated by irradiation leads to a ground state separated from the excited states by an energy gap. Thermal and most of the electromagnetic properties of superconductors are consequences of the energy gap. The electromagnetic properties are dependent on the energy gap are infrared and microwave absorption whose energy range are applied in this work.

The energy gap in a superconductor is carried by the Fermi surface and occurs on either side of the Fermi level (Andrei, 2004). In the figure above, taking superconducting energy gap, $\Delta = 0eV$, to correspond to the position of Fermi surface, E_F, then a maximum of about $700eV$ microwave radiation is absorbed by the cuprate to create a superconducting state evidenced by an energy gap of $\sim 0.13eV$ on either side of the Fermi level and this is the energy required to put the d electrons in the excited state. At the point where the energy gap vanishes, the material reverts to normal implying a transition point. In this research the maximum radiation required to cause the transition is $700eV$. In convention superconductors at T=0, the value of energy gap is $\sim 1meV$. Therefore the value obtained for this work is acceptable for high Tc superconducting cuprates.

Beyond $\Delta = 0.13eV$ the graph reveals development of another energy gap extending to 0.24 eV. It is worth noting that the superconducting state requires the electron pairing and the onset of a long range phase coherence. In low Tc superconductors the long range phase coherence occur due to overlap of wave functions hence have one energy gap. For high Tc superconductors in this case cuprates the long range phase coherence occur due to a mechanism different from overlap of wave functions hence have two distinct energy gaps. The pairing gap, Δ_p and the phase coherence gap, Δ_c. Thus the total energy in the elementary excitation spectrum is given by $\sqrt{\Delta_p + \Delta_c}$.

In this research the use of microwave energy has been employed since in a superconductor conductivity differs substantially from the normal state at frequencies smaller than $\frac{2\Delta}{\hbar}$ and is essentially the same in the superconducting and normal states at frequencies larger compared to $\frac{2\Delta}{\hbar}$. The value of $\frac{2\Delta}{\hbar}$ is in the range of the microwave frequencies.

The second energy gap can also be taken as a pseudogap which usually occur above Tc. The knowledge of energy gap in superconductors is important as it used in the Superconducting Tunnelling equipment (STE), in which the tunnelling current is only possible when the bias voltage reaches the value of $\frac{\Delta(0)}{e}$ (Andrei, 2004). Also the energy gap 2Δ determines the threshold photon energy $\hbar\omega$ which can be absorbed in superconductor. For photons

$\hbar\omega < 2\Delta$ the superconductor has zero resistance at absolute zero but photons of higher energy than 2Δ cause excitations to the unoccupied normal energy states above the gap and the resistance is increased. Between 0-0.12eV, there is a sharp rise in the absorption of radiation. The sharp rise occur at the frequency for which the energy of a photon becomes just sufficient to provide excitations consisting of two electrons.

Makoto Hashimoto et al, have confirmed that the d wave symmetry of superconducting gap has become an accepted fact when one constructs and interprets experimental results. An ARPES study on Bi-2212, (Shen, et al., 1993) is a key experiment which clarified the superconducting order parameter in cuprates. This study compared the energy distribution at the nodes and antinodes. At the antinode, the opening of a gap below Tc was detected as a leading edge shift of the EDC to higher binding energy at the emergency of a sharp quasi-particle peak at $\Delta_k = 30meV$. The result is quite similar to the one obtained in this research with the energy gap opening from 0.6eV-1.0eV though this is as a result of doping while this research is Microwave energy dependent.

C. Transition temperature and energy gap

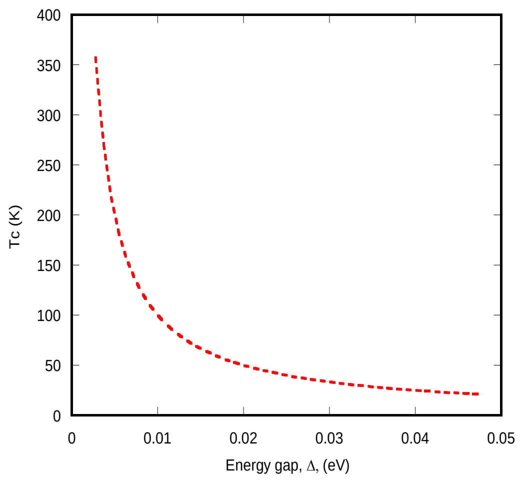

Fig. 3: Graph of variation of transition temperature with superconducting energy gap.

The relationship between Tc and energy gap is nonlinear. Transition temperature varies asymptotically with superconducting energy gap, showing a sharply increasing Tc with reducing energy gap. High values of Tc are obtained at smaller values of energy gap. A value of Tc within the cuprate range (12K-164K), at about 164K gives an energy gap of approximately 0.0075eV. At room temperature (300K), the energy gap is even much smaller, about 0.003eV. At the lowest Tc about 40K at an energy gap of about 0.03 eV.

Increasing energy gap physically imply that many of the free electrons fall in the superconducting state assuming a coherence forming Cooper pairs which enhance the zero resistance conductivity. Critical temperature, Tc in cuprates sets a maximum value of temperature above which coherence of the superconducting state disappears. There exists also another temperature commonly called the pseudogap temperature denoted by T^* which determines the temperature at which the energy gap (2Δ) seizes to exist at Fermi level (Szczesniak, Jarosik, & Duda, 2015). For high Tc superconducting cuprates, the Tc value is achieved at the smallest energy gap of $\cong 0.129$ eV which imply that with reducing energy gap, superconductivity is enhanced hence increased Tc. In fact these results show that the much desired room temperature superconductivity in the potential cuprate class of high Tc's can be achieved with much reduced energy gap of about 0.004 eV.

Conclusion

In this research electromagnetic energy irradiated on cuprates has shown an effect on the superconducting parameters. An electromagnetic energy of $717.47\ eV$ caused an energy gap of $\sim 0.12eV$ above and below the Fermi level (energy gap of $0\ eV$). As the electromagnetic energy reduces to $59.44\ eV$ another energy gap called pseudogap is established and extends to $\sim 0.24eV$ as the energy reduces further to $30.521eV$. This result imply that at a relatively high electromagnetic energy the electrons are set in a coherent phase leading to formation of Cooper pairs. It is also observed that a coherence length of 0.23Å is obtained at an electromagnetic energy of $300eV$. For the cuprate range transition temperature (40 K-138 K) a coherence length of 1.495Å-0.505Å is obtained respectively. The electromagnetic energy needed to cause the d transitions is in the range of $300eV$ since this energy gives the least coherence length that would cause the electrons to pair up and within the range that sets up an energy gap from the Fermi level.

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