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# An analysis and computer simulation of using elastic strain energy to promote superconductivity

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ABSTRACT

Both a model and a computer simulation are developed for superconducting electrons to move by releasing strain energy over mesoscopic distances. Rotation of a grain provides unique strain energy patterns to facilitate conduction. Numerical estimates are derived for the size of the force an electron could exert on the end of a grain to cause it to rotate. The numerical estimates take into account both electric fields and a quantum mechanical rate of change of momentum of the electrons. The force necessary to produce a torque to oscillate a grain at the same frequency of an electron wave packet is found to be in the same range. It is also shown that the magnetic field associated with a normal conducting current can disappear when a superconducting electron moves in the direction of a gradient in strain energy. A computer simulation in C++ shows that strain energy patterns from granular rotation can allow a high degree of electron movement through the center of a grain that has an aspect ratio from 8/7 to 2 and from 10 to 20. The range of tilt angle of the grain that allows electron movement is narrower and lower for higher aspect ratios.


## 1. Introduction

There has been strong evidence to suggest that there is correlation between elastic strain and the maintenance of a superconducting current. A spontaneous strain, for example, has been observed to occur at $T_c$ and affect the energy gap of the Fermi surface of a superconductor [1]. It has also been recorded that in-plane compressive stress lowers $T_c$ in comparison with tension [2], that nanostripe structures are present in currently known high-Tc superconductors [3], and that $T_c$ was found to rise considerably when there was region of zero strain energy in the lattice in front of superconducting electrons [4,5]. Very recently, it has been reported that strain can destabilize static charge strips to enhance the critical temperature $T_c$ [6].

From these previous studies, it appears that control of strain energy might promote superconductivity at the scale of nanograins and the material lattice. Large scale compression and tension on superconducting wires, in contrast, has been shown to suppress superconducting currents at low temperatures [7]. Macroscopic bending strains on superconducting tapes have also been found to lower critical current densities [8].

Offsetting these macroscopic phenomena, this paper offers an analysis of lowering strain energy in front of superconducting electrons on a microscopic scale. By providing the necessary change in potential energy just in front the electrons, it is hypothesized that the electrons will choose to move forward, even in the presence of thermal vibrations, thus broadening the temperature range within which superconductors could be used.

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It is proposed that regions of alternating tension and compression that would provide favorable patterns of elastic strain energy could arise from the slight elastic rotation of the grains themselves. Such rotation has been seen in computational analysis and computer display to produce regions that transition from tension to compression [9,10]. The induced rotational stresses are of the same magnitude as the applied stress originally used to rotate the grains.

The applied stress on the end of an elongated grain that makes it rotate within the material matrix can arise from an externally applied load. What will be analyzed in this study, however, is an applied stress that stems from the superconducting electrons themselves for a self-induced mechanism for conduction.

In the sections that follow, the size of the applied stress available for rotation is estimated from three sources. The first is from electric fields that could be produced by the superconducting electrons. The second is from a rate of change of quantum mechanical momentum of an electron. A total torque that could act upon a grain as a whole to produce the required rotation is then calculated.

It is then shown that the coupling of elastic stress in one direction with elastic stress induced in the opposite direction from the rotation of grains could produce a region of reduced strain energy. Some simple calculations are shown by which the magnetic field can disappear in the presence of elastic strain. Finally, a computer simulation optimizes the orientation and aspect ratio of a rotated grain that allows conduction by lowering strain energy.

## 2. Force available to rotate grains

### *2.1. Applied stress from an electrical field associated with the electron wave packet*

Although no image of the superconducting electrons is readily available, it is expected that several superconducting electrons will be relatively close together at any given time. The analysis here does not exclude the possibility that the electrons are paired and as far apart as the length of a grain. Whatever the arrangement of the electrons, however, their wavelike nature is expected to form a wave packet, within which should be some electric charge. Hence some electric field could be associated with these electrons, as shown in Fig. 1.

Some of the electric field vectors shown in Fig. 1 are expected to interact with those of other electrons and slightly positively charged atoms in the vicinity. An average strength of an electric field, however, is used here and extends through the circular area of radius $R$ in Fig. 1. The electric field is estimated to arise from one charge in the wave packet.

An application of Gauss' Law for the vertical electric field lines above and below the charge in Fig. 1 gives for the magnitude of the electric field E:

$$E \sim \frac{e}{2\varepsilon_0 \pi R^2}. \tag{1}$$

In Eq. (1), $\varepsilon_0$ is the permittivity of free space and e is the fundamental charge on the electron. The grain depicted in Fig. 1 might not be fabricated less than 100 nm in size. The radius $R$ of the circular area on the end of the grain might then be about 10 nm. With this estimate of $R$, the strength of the electric field $E$ becomes $3 \times 10^7$ N/C.

The electric field $E$, if it exists in the form depicted in Fig. 1, could exert a Coulombic force downward on the end of the grain equal to about 2eE. This estimate force follows from a reasonable assumption that the force acts over a 10 by 10 nm area near the end of the grain where there might be a net charge of about 2e from positive ionic charges in the vicinity. The size of this Coulombic force becomes about $1 \times 10^{-11}$ N, which itself is not large. If this force, however, acts on an area of dimensions 10 by 10 nm, the applied stress for rotation becomes nearly 1 MPa, which is a significant local stress. The stress is enough to rotate a grain and provide a particular pattern of strain energy in front of a conducting electron.

### *2.2. Force from a quantum mechanical rate of change of momentum*

This section provides an estimate of the force available to rotate a grain when the force becomes the rate of change of the momentum of the electron. For this analysis, the function $\psi(\vec{r}, t)$ is a wave function related to the probability of finding a superconducting electron in a region of space. A basic definition of the momentum $\vec{p}(t)$ of the electron is then [11]:

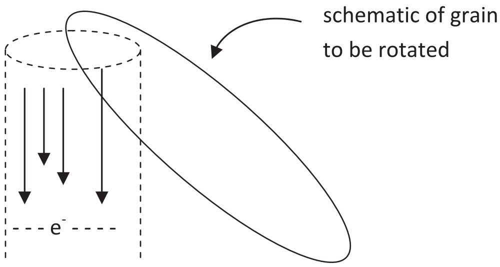


**Fig. 1.** Electric field associated with an electron wave packet that could be used to rotate the elongated grain that is shown schematically.