Review Article

A new process for recording minute disturbances to a crystal

Abstract

We found a process for recording minute disturbances to a crystal that does not involve deposition of energy. It depends on the crystal entering an unstable state during cooling after growth that causes an exothermic phase-change in the crystal when triggered by a transient disturbance to the lattice. Using this recording process, a search for rare events of cosmological origin in 0.3 m3 of mica was made. One was a very high energy event of unknown origin or cause. Adoption of digital recording of images and machine analysis would facilitate searches for evidence of dark matter. Although this recording process cannot be replicated in a laboratory, it is far more sensitive than the etch-track technique. It offers an alternative method to photo-emission for seeking evidence of dark matter. As the crystals of muscovite are mined commercially, they are readily available.

Keywords: disturbances, deposition of energy, lattice, recording process, etch-track technique

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Introduction

Studies of the fossil tracks of charged particles in crystals of the layered mineral muscovite revealed an exquisite and highly sensitive recording process.[1] It responds to adiabatic transient disturbance of atoms by mobile lattice excitations that are created in nonlinear atomic interactions between colliding particles. These self-focussing discrete-particle excitations, called quodons, move at near sonic speed.[2] They are decoupled from phonons and their stability is independent of temperature up to at least 700 K. Using a triple-filter technique to discriminate against conduction currents, it was found they can trap and carry a single unit of charge, of either sign, through metals and insulating materials with minimal loss of energy.[3] When created charge-neutral, there is no know way to detect them within a solid except by their recorded tracks in muscovite. However, they can be detected when they are inelastically reflected at a vacuum interface causing ejection of the last atom at the surface.[4]

Muscovite contains potassium and the ^{40}K isotope is radioactive, with several decay channels. The dominant channel is emission of an electron but it also occasionally emits a positron. Quodons can be created with a positive charge by nuclear recoil in beta decay. Their fossil tracks are recorded during a short geologic time as crystals cool following growth in pegmatites at depths underground exceeding 13 km water equivalent and at temperatures above 700 K.[5] This process can occur only in crystals with about or more than 4 atomic percentage of iron impurity. Figure 1 shows a typical array of their fossil tracks. The passage of a quodon creates individual nucleation sites by assisting Fe ions to migrate to lower energy positions. Subsequently, as cooling continues, the tracks grow in width by accretion, leading to tracks decorated with the mineral magnetite that are visually observable. Duration of recording time depends on variable local environment conditions and size of crystal. It can be estimated from the number of positron tracks recorded and can be of order several tens of years. Evidence was also found for fossil tracks due to electron-positron showers spatially extending over conical crystal volumes, showing the recording and development of the fossil tracks occurred after the crystal had formed and not during its growth.[6]

The beta decay of ^{40}K to ^{40}Ca has a maximum recoil energy of 42 eV. Despite the inevitable lattice defects of dislocations and interstitials, the fossil tracks created by these quodons with a positive charge could exceed 40 cm in length, limited by size of available crystals with suitable composition. Losses of energy to phonons in the creation of quodons resulted in the most energetic quodons having about 10 eV of energy. The decoration on these tracks is continuous, showing no evidence of localized ionization sites. The average rate of energy loss per unit cell of $2.5x10^{-8}$ eV for a track of 40 cm length is inconsistent with nucleation sites due to ionization. Independent evidence for loss-free propagation of quodons was obtained from experiments in which quodons were created by bombarding a solid with He ions. The propagation of quodons of either sign of charge was studied. It was shown that they could propagate at least 2 m in steel and more than 1 km in the synthetic mica fluorphlogopite.[7]

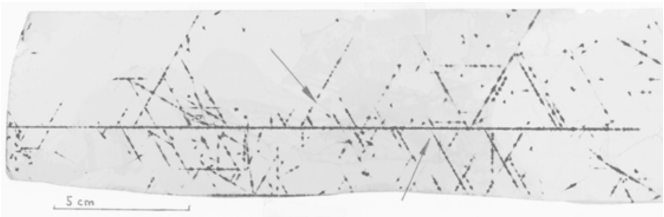

Figure 1 Photo of secondary quodons created by scattering of a primary quodon travelling horizontally. It shows the reduced decoaration with magnetite on the track of a secondary quodon that has not yet trapped a hole, so is uncharged. The actual length of the part of the primary track shown is 23 cm. The decoration of the initial atomc scale track is slow as it involves migration of iron ions in the crystal, which is facilitated by the high temperature of the cxrystal during the recording stage and afterwards.

Figure 1 shows a primary quodon track with many secondary quodon tracks branching from the primary one. They arise from scattering of the primary quodon at crystal defects. Since the positive charge carried by the primary quodon cannot be subdivided, a secondary quodon is initially charge-neutral until it captures a free charge. Yet, as indicated by the arrows, there is evidence of minimal decoration on these sections of tracks. Such weakly decorated tracks can be several cm long, showing that the recording process responds to localized motion of atoms about their equilibrium positions caused by a moving uncharged quodon. The weaker secondary quodons more easily lose their charge before trapping a replacement, leading to alternating lightly and strongly decorated sections of track. As a secondary loses energy by scattering the successive secondaries become too weak to hold a charge and the track ends, dissipating as phonons.

Application to detection of rare cosmic events

Although the existence of fossil tracks of charged particles in muscovite crystals was evident by 1967, it was overshadowed by the elegance of the chemical track-etching technique. In a comprehensive book on this technique, published in 1975, the magnetite fossil tracks in muscovite were interpreted as dislocations despite the obvious difference in scale between them of many million-fold. It contained experimental results on the sensitivity of the etching method, indicating that the least ionizing ion seen to leave an etchable track in mica was 2 MeV ^{20}Ne.[8] Nevertheless, the possibility that rare cosmic events might be recorded in some way in mica, was later studied.[9,10] However, only events detectable by the track-etching technique were considered. This was due in part to the standard practice at a mine, for commercial reasons, of discarding samples of mica that contained visual defects, such as structural striations, colour variations or magnetite ribbons. Also, the cause of the most frequent type of magnetite ribbon, the quodons, was found in the different discipline of nonlinear atomic interactions in collisions. These reasons precluded access to events recorded by the far more sensitive phase-change process.

Recognition of this very sensitive recording process led to a search for tracks or events with unusual properties in samples of mica of total volume 0.03 m^3 or 75 kg, containing about 10^5 quodons tracks. One unique event, which remains unexplained, is shown in figure 2.

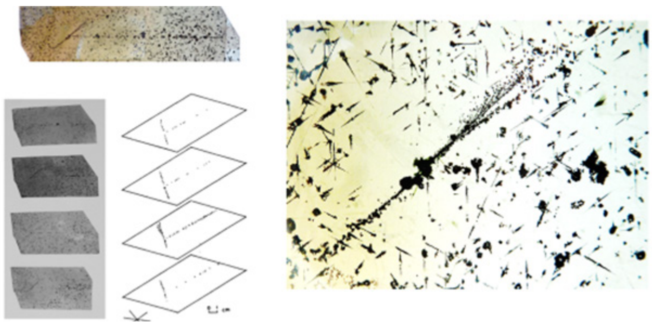

Figure 2 Photos of the rare event and sketch showing its extent over more than 10^5 unit cells in the direction normal to the (001)-plane. It is isolated within the crystal with no connection to the crystal surface by a structural feature, such as a fracture.

The remarkable and puzzling feature of this event is that the structural damage and the long-range jet extends in the direction normal to the (001)-plane of cleavage, over >3.8x10^5 K-planes. This is illustrated in the sketch. The enlarged picture shows the central region: the area of the sheet covered by the picture is 4 x 2.7cm^2. The length of the jet is about 10 cm. The heavy decoration at the centre of the array extends through the thickness of the sheet. It involves about 10^{20} atoms that are replaced by those of magnetite. In addition, there are about 10^{13} atoms involved in the three fractures radiating from the central mass. If each of these changes involve 0.01 eV of energy, then the total energy involved in the event is of order 20 joules. This comes from the crystal during the recording and decoration stages. Unfortunately, the adjacent sheets either side of that with the event were not available, so it is not known if the causative agent left a path or not in the parent crystal. The tracks of other particles and minor disturbances to the crystal recorded in the surrounding regions, show that the major event occurred completely within a crystal. There is no structural connection to the surface of the crystal such as by a fracture.

Another type of rare event is shown in figure 3. It consists of multiple individual decorated dots that show no evidence of interconnection. The array does not lie in any principal crystallographic direction in the (001)-plane. The increase in size of the dots towards the left end might suggest a slowing down of the causative agent. If it were caused by a neutron then the restriction of the array of dots to a single (001)-plane might arise from diffraction scattering.

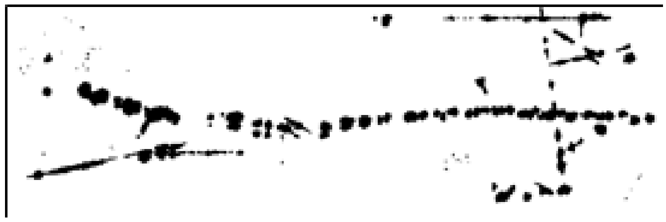

Figure 3 These tracks consist of independent decorated non-connected sites. They invariably are curved and do not lie in crystal-related directions in the (001)-plane. They occur at about the rate of 20 per 0.03 m^3 uring a recording time of tens of years . The length of the track is about 12 cm.

Relevance to detection of dark matter

The possible relevance of mica with >4% of Fe to the detection of dark matter comes from several factors. A recording process that magnifies minute local disturbances of the lattice that makes them observable. The crystals are shielded underground against cosmic background by at least 13 km water equivalent. Individual events that do not involve ionization nor carry a charge can be recorded. The performance of the recording process is verifiable by the presence of positron tracks from decay of ^{40}K in the mica. The duration of the recording stage is variable but can exceed tens of years. Lastly, the recorded information is stable against thermal cycling and is protected from chemical attack.

So far, searches of muscovite crystals to find rare or unique events have depended on visual scanning of sheets of about 1mm or less thickness. The main difficulty is in correlating related events or patterns of the lines in different sheets. This leads to much loss of information. By creating location marks to retain the spatial correlations of sheets cleaved from a crystal, then digitally scanning the sheets followed by image analysis, would be advantageous. Ideally, splitting of muscovite crystals should be avoided until scanning and data collection starts. The total annual global mining of mica minerals is about 1.2 million tons, of which 27% is used in electronics and electrical applications. About 30% of this could have the required iron content necessary for phase-change recording. Crystals for study need to be size grade 1 or larger and are more likely to be damaged in mining. Since sheets of possible interest must show evidence of magnetite decoration of tracks, they will be of lower commercial value.

Conclusion

Large crystals of muscovite mica grow in pegmatites at temperatures exceeding 700 K that are formed at least 5 km underground near a source of magma. Crystals that contain at least 4 atomic percentage of an impurity of iron can record minute perturbations of the crystal due to an external agent. As crystals cool but remain at a high enough temperature to allow migration of Fe ions, they become unstable in attempting to reach a lower energy state by expelling the iron. This is achieved by a phase-change, triggered by an external agent, leading to formation of micro-crystals of black magnetite. Owing to weak van der Waals bonding in the vicinity of the potassium sheets sandwiched between silicate layers, the pegmatite crystals form thin ribbons in the potassium (001)-planes. The recording period is of order several tens of years. Further slow cooling allows migration of Fe to decorate the initial nano-scale tracks and make them visible. These ribbons are

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stable against thermal cycling and are protected chemically within the bulk crystal. This results in the information held in the ribbons or dots being stored unchanged for geologic times. Measurements on the distribution and shape of magnetite ribbons showed that they were produced by moving positive charges, either relativistic particles or mobile, discrete-particle, lattice excitations called quodons. These excitations move at near sonic speed through any solid material with minimal loss of energy. They arise from nonlinear interactions between colliding swift particles in the mica. Independent studies of quodons show that they can propagate more than 2 m in steel and 1 km in synthetic mica fluorphlogopite, move ballistically and tolerate minor lattice defects resulting in near loss-free propagation. The phase-change recording process can be triggered by adiabatic transient displacements of atoms from their equilibrium positions. This recording process is many orders of magnitude more sensitive than the track-etching technique and does not involve energy input as required for detection by emission of photons. Adoption of digital recording of images and machine analysis would facilitate searches for evidence of dark matter.

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Conflicts of interest

The author declares there is no conflict of interest.

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