Absorbance and transformation of SHF electromagnetic waves in quartz-containing heterogenic materials

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Abstract. A study of the mechanism of uptake and conversion of microwave energy into heat energy is presented. The term "SHF – trigger", which activates at the atomic, electronic, and molecular scales, is introduced for the mechanism of micro cracking, destruction, and crashing of quartz-containing rocks. It has been found that the uptake and conversion of microwave energy into heat energy begins there were some criteria of the sample instability in energy consummation are satisfied. This mechanism of the energy conversion with the heating effect differs from other modes of heating by its efficiency; accordingly, a special criterion is required. The loss tangent of a dielectric, such as mineral or heterogeneous rock, could serve as a measured parameter. This parameter is attributed to slowly establishing modes of relaxation, which manifest themselves in the presence of polar molecules, complicated anion radicals, chemically bounded water, solid/liquid interfaces, borders of dielectrics and conductors. In addition, a new mechanism of conversion of microwave energy into heat energy in points of contact between water-saturated pores in model specimens was suggested.

1. Introduction

Various aspects of the trigger effects which manifest themselves in geosphere, geo-mechanical systems, and anthropogenic facilities being in critical state, as well as their impact on the system atmosphere/ionosphere plays a significant role in nature [1].

Investigations of the effect of the SHF irradiation on matter started in 1980 [2] but it remains insufficiently studied in various domains of science up to now. The heating effect of the dielectric properties of minerals and rocks subjected to the SHF exposure is given in a review [3]. A ruby crystal was heated by SHF irradiation up to 1500ºC. The authors observed changes in color, optical range, etc. after the experiment [4]. These results evidenced the significance of the electromagnetic waves impact but did not elucidate the mechanism of the process. In [5-7], the electric fields in natural dielectrics excited by either mechanical loading or electric polarization were studied. It was shown that the relaxation of the polarization is identical under both kinds of stimulation and is thermo activated in nature. Temperature dependence of the time relaxation of electric field was established, and the activation energy of charge carriers’ motion was evaluated.

In this work, the uptake and conversion of microwave energy into heat energy is considered as a trigger phenomenon. In addition, some theoretical implications and analyses taken from my recent works as well as those of other authors will be considered. The SHF-induced mechanism of fracture (“SHF-trigger”) in quartz-containing rocks and criteria of instability of SHF-waves-absorbing materials are ill-studied. The elaboration of these mechanisms could explain nature of the transformation of
electromagnetic waves into the heat energy and promote a new direction in the field of investigations of strength, fracture, and longevity of solids.

In Ref. [8], the criteria of mechanical instability of SHF-wave-absorbing samples were experimentally studied in order to determine the efficient parameters of the SHF energy needed for crashing quartz-containing rocks issuing from the dynamics of microcracking. The experiment was carried out by the Ioffe Institute together with the St Petersburg Mining University. The forming of the field of the uniform temperatures were established using a special apparatus equipped by magnetron and waveguide [9,10]; the dependence of granite ultimate strength on temperature was obtained (Figure 1) [8].

![Figure 1](image)

Figure 1. Granite ultimate strength versus temperature under the “SHF-trigger” (more detailed [8]); a – compression test 1, 2, 3, 4, 5; b – tensile test 1, 2, 3, 4, 5.

Basing on this experiment (Figure 1), one should conclude that some mineral components absorb the electromagnetic energy more rapidly than other (2-3fold). Correspondingly, the non-uniform expansion of different components occurs that causes a variation of inter phase boundaries, appearing of microcracks, and strength reduction of a heterogenic material (Figure 1). Thereafter, the microcrack tips are capable to stimulate the crossing of dislocation and increasing of the sample decomposition rate in dependence of the applied technology and SHF field exposure time. The mechanism of the transformation of the SHF field energy into the heat energy is based on the emission of the “bound charges” polarization heat.

2. Absorbing and transformation of the microwave energy

The transformation of the SHF field energy into the heat energy is based, mainly, on the polarization of three kinds (Figure 2) [11]. The first kind is the electronic (optical) one. In such a case, the absorbance of the microwave energy could be performed by nonpolar molecules yet. Under the action of the external field, forces directed away from a nucleus (Figure 2a). The second kind of polarization is the ionic one: positive ions deviate along the field direction. The third kind of polarization is the ionic polarization: positive ions deviate along the field direction while the negative ones deviate to the opposite side.

![Figure 2](image)

Figure 2. Kinds of polarization; a– electronic, b – dipole, c – ionic.

3. Water-saturated pores in quartz-containing solids and another mechanism of transformation of the SHF field energy into the heat energy differing from the three above mentioned mechanisms.

Porous and crackly rocks contain always more or less quantity of water. A distinction is made between bound and free water. The chemically bound water as well as other molecules and ions is a part of the
crystalline lattice of minerals. Removal of such water results in material decomposition with its transformation into another (water-free) state. A presence of the chemically bound water in a rock manifests itself when heating the rock. The water affects the rock properties at high temperatures. In consequence of the distorting of the crystalline lattice of minerals because of removing of the chemically bound water results in the rock decomposing and loosening, though in certain cases the hardening could be observed (clay). The physically bound water is tightly compacted with hard particles with filming them due to the attraction forces. The physically bound water does not migrate in rocks. It is characterized by the high density (up to 1.74 g/cm$^3$), low point of congelation (−78°C), heat capacity, electrical conductivity. This water is not solvent; it can be removed from a rock by heating up to 110°C. That is why; the presence of physically bound water affects considerably the physical properties of rocks.

The free water might be either in the form of capillary water, which is hold by force of capillary ascension or as gravity water that fills out large pores and move under the action of gravitation or pressure head. The water content is assessed by the value of capillary water capacity, which depends on an average size of pore channels that are situated normally to the ground water surface in the given volume. So, the sand contains, mainly, the capillary water, while the clay, loess, and clayish soils are filled with both molecular and capillary water. The relative content of the capillary water in granites is of 3 to 11%. The higher the molecular water capacity of rocks, the lower their water yield. The water yield index depends on the size of rock-forming, pore size, and mutual arrangement of pores. As a rule, the low water return of pores reduces the productivity of mechanical and hydraulic mining, hinder drainage, transportation, and shattering of a deposit [12]. There is also another mechanism differing from three above mentioned and grounded on model experiments [13,14]. The latter mechanism is illustrated in Figure. 3: the SHF energy is transformed into the heat energy by means of two high-frequency rod electrodes (Figure. 3a) [13]. Figure 3b shows a photograph, in which yellow-red color (heating) appears between two bolls. Though this model mechanism differs from polar kinds of mechanisms, all described mechanism could manifest themselves under certain condition.

![Figure 3](image_url)

**Figure 3.** a – Scheme of the model experiment on microcrack advancing in accordance with suggested SHF-trigger mechanism in a hard-rock block with two high-frequency rods (scheme of a computational domain: d / L = 0.4; grid 15 × 15 × 10 cells) [13]; b - photograph and scheme of the model of the SHF mechanism in a microwave apparatus; yellow-red color (heating) appears between two plastic contacting bolls filled with water [14].

When being enabled, a microwave becomes blocked inside the polystyrene balls filled by water (like water saturated pores in a sample) [14]. The SHF wave jumps back wall-to-wall similarly, the total light reflection with generating resonant vibrations. If the ball is alone, then the heating would be in the ball center. If two balls touch one another, the heating would be in the place of their contact. In the case of a great amount of balls, the places of contact heat with associating the neighboring water containing balls (water-saturated pores in a sample). In addition, luminescence (lighting, plasma (Fig. 3b) could be considered as a new light source mechanism (this effect could be of interest in lithography). Factually, this mechanism results in pore and pore pressure increasing, microcracking and degradation of materials. The suggested SHF-trigger mechanism starts at the atomic,
electronic, and molecular scale levels in accordance with fundamental laws of nature under the action of electromagnetic waves. When being an object in the SHF field, the SHF-trigger mechanism could be regarded as activated, and the further state of the object determines its absorbing capacity and exposure time. It has been mentioned above that the SHF-trigger is setting into action by either single, or double, or ternary kinds of polarization. The model mechanism includes some conditions of the SHF-trigger activation that is 1) the presence of water-bearing liquid, 2) the total (or partial, no matter) volume of liquid, 3) each ball must have a cover and contact points with other balls; otherwise, a single arbitrary-shaped center with a boundary edge could be considered. The heating gets going in contact with places, however, the principle of the mechanism is uniform: a wave is blocked and a similar resonance with heating effect arises in contact points (in the center in the case of a single ball). It has to be noted that though all mechanisms of SHF electromagnetic waves generation are characterized by different power, frequency, wavelength, and operating time in dependence of the structural and chemical composition, this variability does not affect the activation of the SHF-trigger. The main feature that governs the microwave energy transformation in the heat energy is the loss tangent of a dielectric which serves as the quantitative characteristics.

To understand the essence and for visibility we shall consider vector diagram for measuring $\tan \delta$ under ideal condition (Figure. 4) that is under the lack of outer electromagnetic field.

**Figure 4.** a – vector diagram for measuring $\tan \delta$ under ideal condition (under lacking outer electromagnetic field); b – vector diagram, in which $I_{\text{react}}$ is the capacitive (reactive) current, $U_{\text{external}}$ is the outer voltage, $I_{\text{act}}$ is the active current is the vector summation, and $I_{\text{react}}$ is the reactive current, $I_{\text{infl}}$ is the vector of effect current.

In order to be certain the lacking of effect of outer fields when measuring $\tan \delta$, two measurements shout be carried out: the first measurement is performed at the “positive” value of the exciting voltage (phase of 0° in default) while the second one is performed at the “negative” value of the exciting voltage after switching over 180° the exciting voltage phase.

At the above shown vector diagram, the vectors and angles with signed magnitude “+” correspond to measurements performed at the “positive” value of the exciting metering circuit voltage, while the vectors and angles with signed magnitude “−” correspond to measurements performed at the “negative” value of the exciting voltage. If the measured values of the loss tangent of a dielectric are equal in value then there are not outer electrical fields. As can be seen from Figure 4, the angles are equal (+ $\delta = -\delta$), hence, $\tan \delta = -\tan \delta$. In the case of the action of the outer electromagnetic field of considerable strength upon isolation of a monitoring object, the voltage of the outer electromagnetic field affects the isolation in addition to the exciting voltage thus stimulating the effect current flowing through isolation of the monitoring object. In a general way, the frequency and phase of the effect current $I$ do not coincide with the frequency and phase of the exciting current. In order to simplify the comprehension of the process course during measuring $\tan \delta$ under condition of outer electromagnetic field affection, the following special case will be considered below.
Let us assume that the effect current frequency coincides with that of exciting current frequency of the isolation of measuring object but differs in phase. Let us construct a vector diagram for this case on the assumption of that the outer field voltage in the measuring scheme of the loss tangent of a dielectric $U$ (in Figure 4a an arbitrary angle of $40^\circ - 45^\circ$ is shown). The outer voltage $U_\text{ex}$ induced capacitive (reactive) effective current $I_\text{react}$, which advance in $90^\circ$ this voltage, will go through isolation of the measuring object, as well as the active current $I_\text{act}$ that is in phase with the outer voltage, $I_\text{react}, I_\text{act}$. A composition of vectors of active ($I_\text{act}$) and reactive ($I_\text{react}$) components results in an effective current vector $I_\text{infl}$ (Figure 4b). A sum of the effective current $I_\text{infl}$ and the exciting current $+I$ causes a rotation of the loss dielectric angle $+\delta$ through an angle of $\Delta$, thus introducing an error in measured loss tangent of a dielectric at “positive” exciting voltage because a measured value would not be equal to $+\tan\delta$ [15]. From this it follows that the SHF-trigger cannot be activated neither by applied outer mechanical deformation, nor distortion of crystalline lattice, stress in defect structures, dislocations, the fluctuations, convection heating, phonon vibrations. Mechanisms of SHF-trigger might be activated only by the action of SHF electromagnetic waves.

4. Conclusion
It stands to mention the scientific explicability and relevance of both the term SHF trigger and new mechanisms. The lack of the effect of SHF trigger might be useful for determination or exclusion of this source of heat as well as to be actual for ore mining and dressing plants when introducing gas-liquid components of degradation of crystals and minerals. The microwave theory of fracture and mechanism of absorbance and transformation of SHF electromagnetic waves into heat (SHF-trigger mechanism) is put for the first time and considered as important and novel prospect in investigations of fracture of solids along with other methods.

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