ACOUSTICAL EXCITATIONS OF $YBa_2Cu_3O_{7-x}$ POWDERS IN A GRAVITATIONAL FIELD

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The angular distribution functions of 002 reflection intensities by means of X-ray pole figure peaks investigation in the pressed $YBa_2Cu_3O_{7-x}$ powder surrounding was measured. Broad peaks in the mentioned distribution functions were detected in the case, when the sound wave of a some typical frequencies had propagated across the powder before the measurement. The peaks appearance could be a consequence of preferred orientation of the particles basal planes inside the powder. The problem of sound waves propagation inside $YBa_2Cu_3O_{7-x}$ powder placed in gravitational field has been solved. It can be seen from the presented theoretical analysis, that quasi-orientation effect of particles inside the powder can be expected during the sound wave propagation if the conditions are suitable. A simple method of sintered bulk $YBa_2Cu_3O_{7-x}$ material preparation can be proposed on the basis of the mentioned principle.

INTRODUCTION

Quasi-two dimensional anisotropy is one of the key elements characterizing the superconductivity in layered perovskite cuprate materials. As the family of cuprate high T_c materials grows, it has become apparent that the degree of anisotropy varies considerably among them. $YBa_2Cu_3O_{7-x}$, whose superconducting anisotropy was experimentally accessed in an early stage [1,2], has turned out to be one of the least anisotropic members of the high T_c family.

The degree of anisotropy is expressed by a parameter γ, which is the ratio of the coherence lengths parallel and perpendicular to the basal plane direction. In the anisotropic Ginsburg-Landau model, this quantity is the square root of the effective mass ratio, $\gamma = (m_c / m_a)^{1/2}$, where m_a and m_c are the effective masses for the electron motion within the basal plane and in the c direction, respectively. As regards $YBa_2Cu_3O_{7-x}$, various experimental methods including resistive [1-8], magnetic [9] and torque [10] measurements to probe the anisotropy have provided generally consistent results, with the values of γ falling between 5 and 10.

While the predominant anisotropy in the layered cuprates is between the c-axis and the ab-plane, anisotropy within the ab-plane is also present due to their orthorhombicity. The conductivity along the b-direction (parallel to the CuO chain) is greater than the conductivity along the a-direction [11,12,13,14].

The anisotropy of the Hall effect has been obtained in $YBa_2Cu_3O_{7-x}$ superconductors. Most of the Hall measurements are done with transport current in the basal plane and magnetic field applied along the c-direction. The Hall data for other field and current configuration are not abundant, but reported data seem to show consistency. It was obtained a negative value of Hall coefficient with magnetic field applied perpendicular to the c-axis much smaller in magnitude than that for $H // c$-axis [3,8,15].

The mentioned anisotropy usually disappears in sintered $YBa_2Cu_3O_{7-x}$ bulk materials prepared by heating process of pressed powder as a consequence of divers orientation of single particles in powder. The basal plane direction inside the particle unit is determined by the characteristic shape of particle (figure 1).

EXPERIMENTAL PART

Sound waves from broad interval of frequencies were propagated across $YBa_2Cu_3O_{7-x}$ powder and the powder was pressed by 150 MPa subsequently. Angular distributions of particles c-axis orientation in pressed samples were investigated by means of X-ray pole figure peaks obtained from the 002 reflection. There it is possible to find a preferred direction of single particles *c* axis orientation on the basis of used technique.

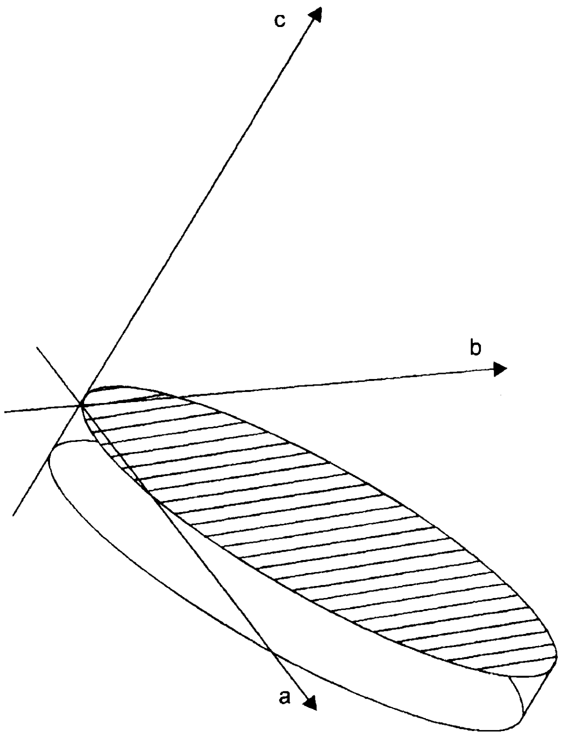


Figure 1. $YBa_2Cu_3O_{7-x}$ particle

Distribution functions for samples prepared from the pressed powder exposed by acoustical waves of frequency 50 Hz during 1 and 20 hours are shown in figure 2. As it can be seen no direction is preferred from the 002 orientation point of view. No change inside the powder can be observed during the 50 Hz acoustical waves propagation inside the powder. It can be concluded, that the frequency 50 Hz is too low and transport of mass does not occur.

The direction -6^0 is apparently preferred in the case of the frequency 500 Hz, as can be seen from figure 3. A broad peak in the angular dependence of the 002 reflection intensity was observed from both surface and volume of the sample. Most of the particles basal planes are oriented in horizontal level in the entire volume of the pressed powder.

The distribution function in the case of acoustical waves of frequency 1000 Hz is shown in figure 4. No peak can be observed in the curve and no direction is preferred consequently.

As can be seen from presented results, it is suitable to expose the powder by acoustical waves of frequency about 500 Hz before technological process. Vertical direction is preferred from the particles c-axis orientation point of view in that case inside the pressed powder.

Quasi-orientation effect of the particles observed during mentioned process could have considerable signification for technology of sintered material.61.3

THEORETICAL PART

As can be easily shown, $YBa_2Cu_3O_{7-x}$ single particles have a shape of flat plates and divers orientation of particles may be observed inside the powder. The $YBa_2Cu_3O_{7-x}$ single particle is shown in figure 1. The basal plane is oriented parallel with plates plane and *c*-axis is perpendicular.

The considered system (powder) have been consisting of both subsystem of particles and subsystem of interspaces (holes) among the particles respectively. The holes of any shape and size can be placed around each particle in the state of equilibrium. We consider changes inside the powder joined with the redistribution of the system. Particles of the powder can penetrate to the "holes" during the changes. Mentioned process of the particles penetration is usually joined with changes of position and orientation of single particles inside the powder. Of course, the possibilities of the penetration depends on the local conditions and the local conditions change during the process subsequently.

We have achieved the redistribution of the system mentioned above by means of the sound wave propagation across the powder. The particles of the powder was exposed by periodical mechanical shocks during the sound wave propagation and the changes of the particles orientation can be expected consequently. It could be suitable to find a method for description of mechanism of the process. That is not clear, if it could be advantageous to describe the stochastic process of the changes by description of single particles and holes movements.

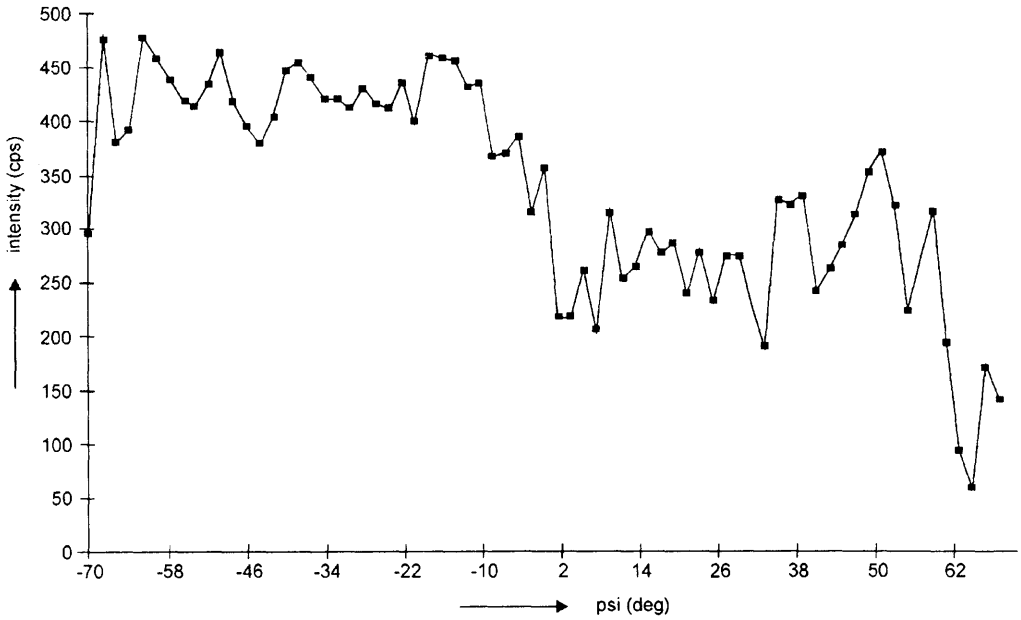
As it can be shown, it is more simple to investigate the problem from the transport of energy point of view. Structure of the system is defined by actual spatial arrangement and orientation of particles. Each particle must be placed in its own position inside the powder by means of some interparticles interaction (coupling mechanism) generated in powder. The structure of the system can be changed (destroyed) by sufficient energy applied from outside environment. "Development" of the system (powder) depends on energy of the transported mechanical waves.

The acoustical waves can generate changes in powder. Which kind of changes it could be, it depends on relationship of energy of mechanical waves and energy of coupling mechanism (figure 5):

1. If the acoustical waves energy is higher then the coupling mechanism energy ($\omega > \omega_0$), too much energy is supplied to the powder system and disorientation effects of particles can be expected.
2. In the case, if the acoustical waves energy is even equal to the coupling mechanism energy ($\omega = \omega_0$), the energy of the powder system does not increase in a gravitational field and spontaneous changes can be expected.
3. If the coupling mechanism energy is lower than the acoustical waves energy ($\omega > \omega_0$) no changes can be expected.

The spontaneous changes in the second case gradually lead to the most stable state of the system - to the state with minimal energy in the gravitational field. Most of the particles in $YBa_2Cu_3O_{7-x}$ powder are oriented in horizontal level in mentioned state shown in figure 7).

a)



b)

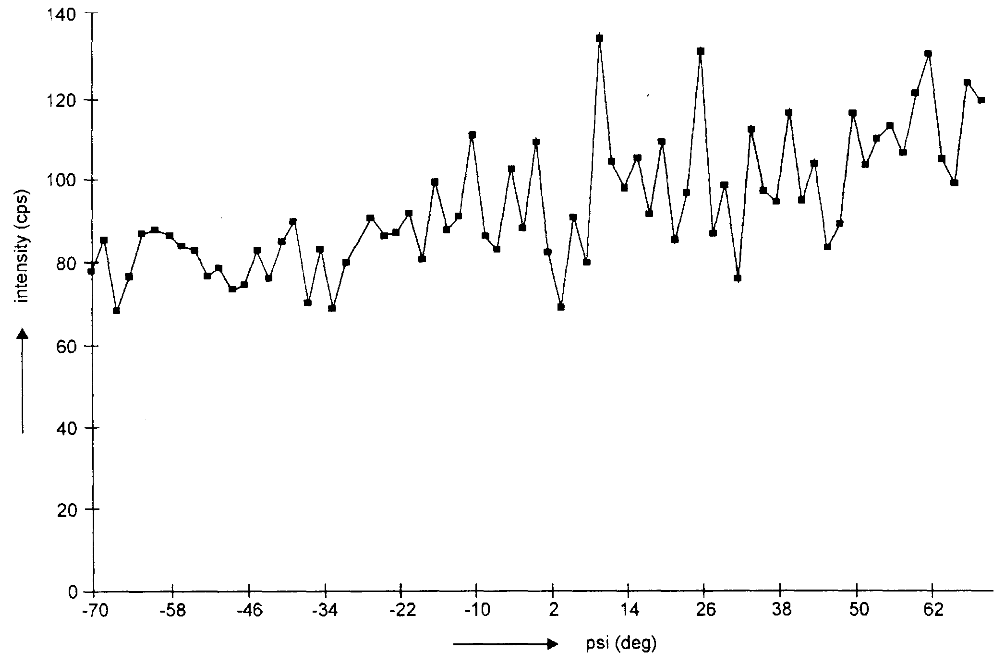
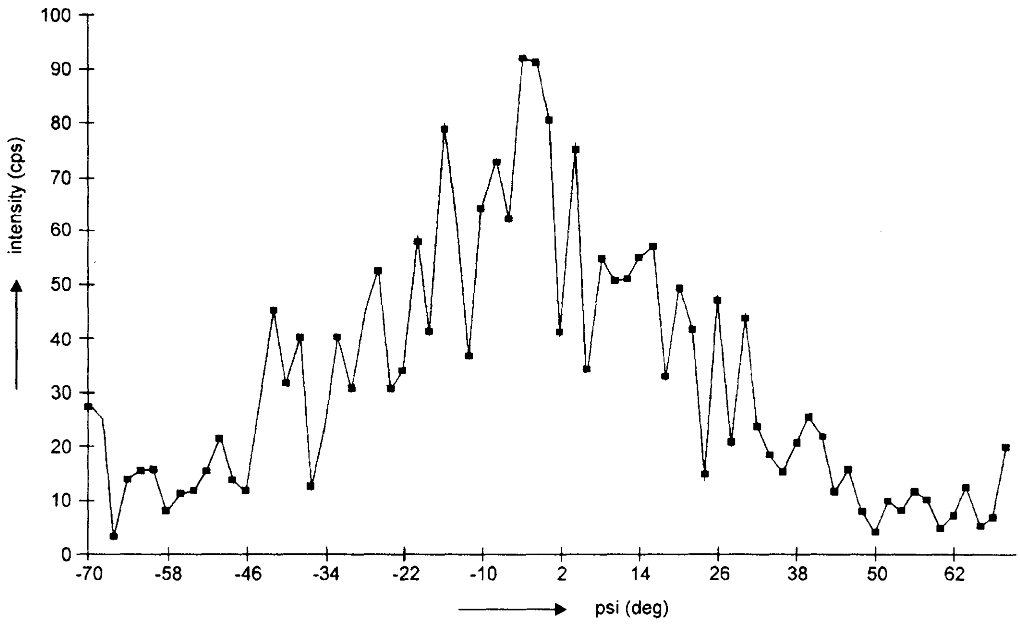


Figure 2. Angular distribution of 002 reflection intensity in surrounding area of pressed powder exposed by acoustical waves of frequency 50 Hz.
a) during time interval 1 hour, *b*) during time interval 20 hours

a)



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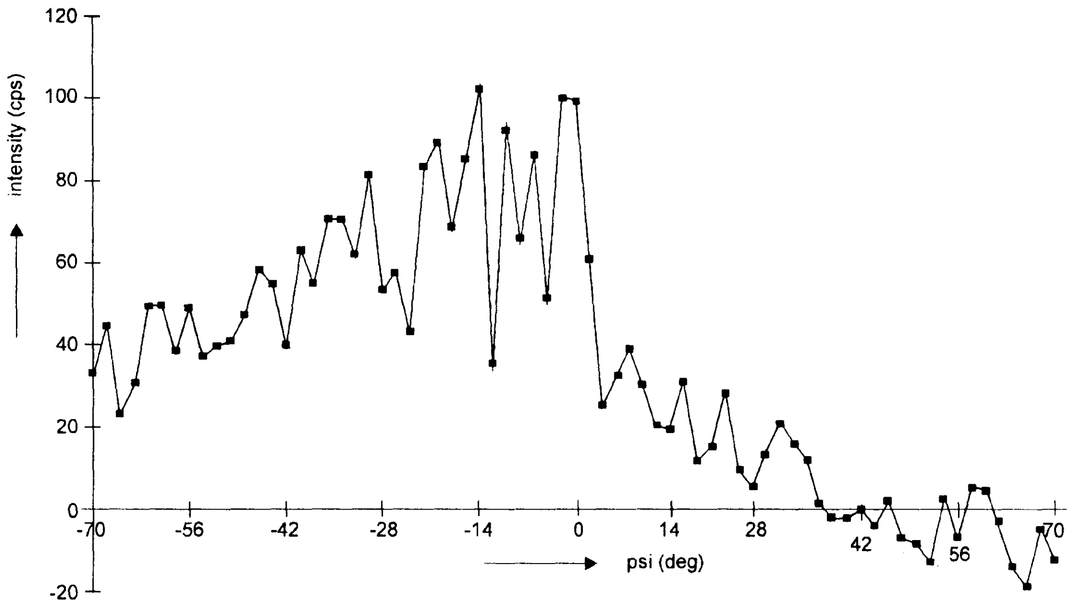

Figure 3. Angular distribution of 002 reflection intensity for the sample prepared from powder exposed by acoustical waves of frequency 500 Hz during time interval 1 hour.
a) measured from surface of sample, *b*) measured from volume of the sample

Analysis of energy transport across the powder

Particles create a "empty spaces" (holes) among them by their actual arrangement inside the powder. Whole volume of "empty space" depends on sizes, shapes and spatial orientation of particles. Average value of the powder mass density is defined by arrangement mentioned above.

Any particle must be coupled in its own position by some interparticles forces generated inside the powder. It has been necessary to consider the coupling mechanism on the particle level under present conditions for description of energy transport.

The spatial changes of both the local mass density average value and the local interparticles coupling mechanism can be observed as a consequence of inequable particle distribution inside the powder. We suppose, that the problem of energy transport across the powder can be solved by well known methods but the spatial changes of both the local mass density value $\rho(\vec{r})$ and the constant value characterized the local interparticles coupling forces $E(\vec{r})$ respectively must be considered.

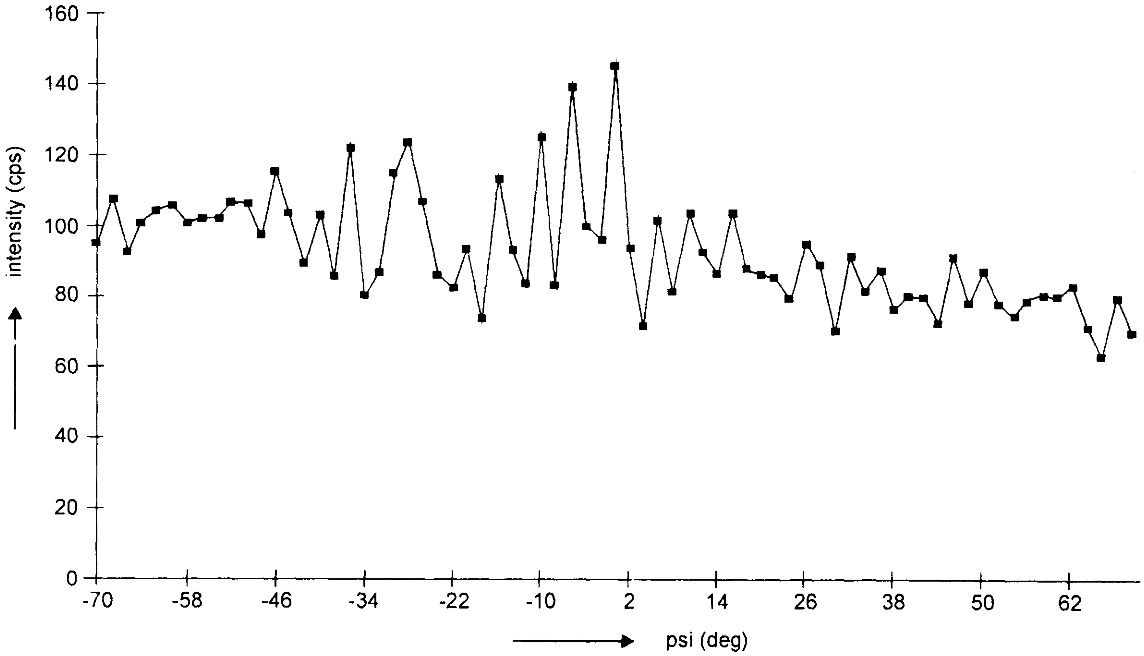

Figure 4. Angular distribution of 002 reflection intensity for the sample prepared from powder exposed by acoustical waves of frequency 1 kHz during time interval 1 hour.

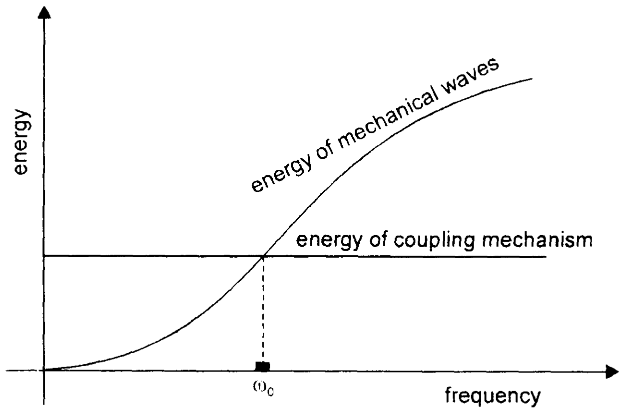

Figure 5. Scheme of relationship between energy of acoustical waves and coupling mechanism energy.

We took into account spatial changes of $\rho(\vec r)$ and $E(\vec r)$ and solved this problem by known technique. Note, that $\rho(\vec r)$ and $E(\vec r)$ are functions of coordinates $\vec r = [x, y, z]$. In this case, operators for canonical variables of the oscillating powder can be written by well known form:

$$\hat Q(\vec r) = \sum_{\vec w} \frac{1}{\sqrt{V}} \sqrt{\frac{\hbar}{2\rho(\vec r)\omega_{\vec w}}} \{e^{i\vec w.\vec r}\hat b_{\vec w} + e^{-i\vec w.\vec r}\hat b^+_{\vec w}\}; \tag{1a}$$

$$\hat\pi(\vec r) = \sum_{\vec w} \frac{i}{\sqrt{V}} \sqrt{\frac{\hbar\omega_{\vec w}\rho(\vec r)}{2}} \{-e^{i\vec w.\vec r}\hat b_{\vec w} + e^{-i\vec w.\vec r}\hat b^+_{\vec w}\} \; . \tag{1b}$$

With the aid of inversion of (1a,b), can be find expressions for operators $\hat b_{\vec w}$ and $\hat b^+_{\vec w}$:

$$\hat b_{\vec w} = \sqrt{\frac{\omega_{\vec w}}{2\hbar V}} \int_{(V)} dV \sqrt{\rho(\vec r)}\, e^{-i\vec w.\vec r}\hat Q(\vec r,t) + i\frac{1}{\sqrt{2\hbar V\omega_{\vec w}}} \int_{(V)} dV \frac{1}{\sqrt{\rho(\vec r)}}\, e^{-i\vec w.\vec r}\hat\pi(\vec r,t) \tag{2}$$

$$\hat b^+_{\vec w} = \sqrt{\frac{\omega_{\vec w}}{2\hbar V}} \int_{(V)} dV \sqrt{\rho(\vec r)}\, e^{i\vec w.\vec r}\hat Q(\vec r,t) - i\frac{1}{\sqrt{2\hbar V\omega_{\vec w}}} \int_{(V)} dV \frac{1}{\sqrt{\rho(\vec r)}}\, e^{i\vec w.\vec r}\hat\pi(\vec r,t) \tag{3}$$

and shown following commutator relations:

$$\left.\begin{aligned} &[\hat b_{\vec w}, \hat b^+_{\vec w'}] = \delta_{\vec w,\vec w'} \\ &[\hat b_{\vec w}, \hat b_{\vec w'}] = 0 \\ &[\hat b^+_{\vec w}, \hat b^+_{\vec w'}] = 0 \end{aligned}\right\} \tag{4}$$

Hamiltonian $\hat H$ of system is defined by formula:

$$\hat H = \frac{1}{2}\int_{(V)} \frac{\hat\pi(\vec r)^2}{\rho(\vec r)} dV + \frac{1}{2}\int_{(V)} E(\vec r)(\nabla\hat Q(\vec r))^2 dV \tag{5}$$

After substituting of equation (1b) to first integral of (5) we obtain:

$$\frac{1}{2}\int_{(V)} \frac{\hat{\pi}(\vec{r})^2}{\rho(\vec{r})} dV = -\frac{\hbar}{4}\sum_{\vec{w}}\sum_{\vec{w}'}\sum_{n=1}^{4} \sqrt{\omega_{\vec{w}}\omega_{\vec{w}'}}(-1)^{s_n+n}\frac{1}{V}\int_{(V)} e^{i[-(-1)^{s_n}\vec{w}-(-1)^{n}\vec{w}'].\vec{r}} dV \hat{B}_{n,\vec{w},\vec{w}'} \tag{6}$$

where operator $\hat{B}_{n,\vec{w},\vec{w}'}$ is given by:

$$\hat{B}_n = (\hat{b}_{\vec{w}})^{x_n^{(-)}} (\hat{b}^+_{\vec{w}})^{x_n^{(+)}} (\hat{b}_{\vec{w}'})^{y_n^{(-)}} (\hat{b}^+_{\vec{w}'})^{y_n^{(+)}} \quad ; \quad x_n^{(\pm)} = \frac{1}{2}[1\pm(-1)^{s_n}] \; ; \quad y_n^{(\pm)} = \frac{1}{2}[1\pm(-1)^{n}] \; ; \quad \text{and } s_n = \sum_{m=1}^{n} m \; : \tag{7}$$

We took into account the facts, that:

$$\frac{1}{V}\int_{(V)} e^{i[-(-1)^{s_n}\vec{w}-(-1)^{n}\vec{w}'].\vec{r}} dV = \delta_{-(-1)^{s_n}\vec{w},(-1)^{n}\vec{w}'} \; ; \quad \omega_{\vec{w}} = \omega_{-\vec{w}} \tag{8}$$

and then expression (6) becomes:

$$\frac{1}{2}\int_{(V)} \frac{\hat{\pi}(\vec{r})^2}{\rho(\vec{r})} dV = \frac{\hbar}{4}\sum_{\vec{w}} \omega_{\vec{w}} (\hat{b}_{\vec{w}}\hat{b}^+_{\vec{w}} + \hat{b}^+_{\vec{w}}\hat{b}_{\vec{w}} - \hat{b}_{\vec{w}}\hat{b}_{-\vec{w}} - \hat{b}^+_{\vec{w}}\hat{b}^+_{-\vec{w}}) \; . \tag{9}$$

For determination of Hamiltonian (5) it is necessary to find gradient of operator (1a), put to square the gradient and next substitute the square of gradient to second integral in (5):

$$\frac{1}{2}\int_{(V)} E(\vec{r})[\nabla\hat{Q}(\vec{r})]^2 dV = \frac{\hbar}{4V}\sum_{\vec{w}}\sum_{\vec{w}'}\sum_{n=1}^{4} \frac{1}{\sqrt{\omega_{\vec{w}}\omega_{\vec{w}'}}} \left(\int_{(V)} F_n(\vec{r},\vec{w},\vec{w}')e^{i[-(-1)^{s_n}\vec{w}-(-1)^{n}\vec{w}'].\vec{r}} dV\right)\hat{B}_{n,\vec{w},\vec{w}'} \tag{10}$$

Operator $\hat{B}_{n,\vec{w},\vec{w}'}$ is defined by (7) and functions $F_n(\vec{r},\vec{w},\vec{w}')$ can be written as:

$$F_n(\vec{r},\vec{w},\vec{w}') = \frac{E(\vec{r})}{\rho(\vec{r})}\left[-\frac{1}{2\rho(\vec{r})}\nabla\rho(\vec{r}) - (-1)^{s_n} i\vec{w}\right]\cdot\left[-\frac{1}{2\rho(\vec{r})}\nabla\rho(\vec{r}) - (-1)^{n} i\vec{w}\right]. \tag{11}$$

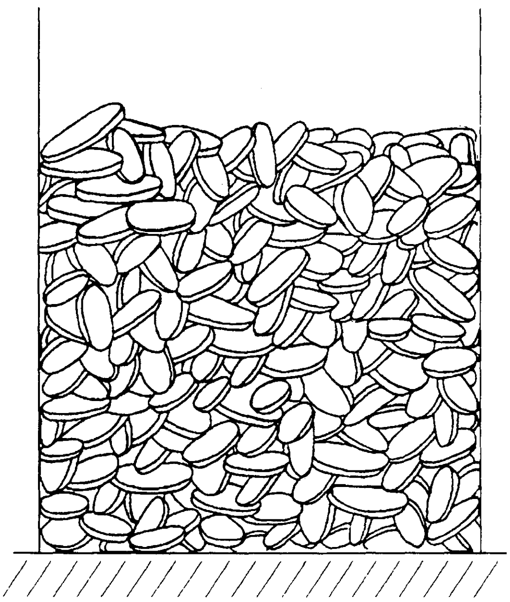

Figure 6. Scheme of $YBa_2Cu_3O_{7-x}$ powder system, which was not exposed by sound wave propagation. No direction is preferred from the particles orientation point of view.

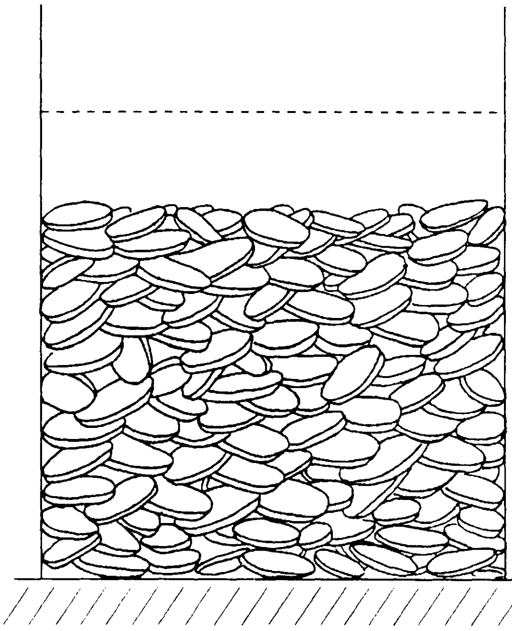

Figure 7. Scheme of $YBa_2Cu_3O_{7-x}$ powder system exposed by sound wave of "optimal frequency" propagation. Transported energy is equal to energy of coupling mechanism and the spontaneous changes are generated. The changes gradually lead to state of minimal energy. Most powder particles are oriented close to horizontal level in that state.

We perform Fourier transform of functions (11):

$$F_n(\vec{r},\vec{w},\vec{w}') = \sum_{\vec{K}} d_{\vec{K}}^{(n)} e^{i\vec{K}.\vec{r}} \ , \quad d_{\vec{K}}^{(n)} = \frac{1}{V} \int_{(V)} F_n(\vec{r},\vec{w},\vec{w}') e^{-i\vec{K}.\vec{r}} \, dV \tag{12}$$

and then substitute these functions to expression (10). Coefficients $d_{\vec{K}}^{(n)}$ can be written as:

$$d_{\vec{K}}^{(n)} = D_{\vec{K}} + i \, [(-1)^{s_n}\vec{w} + (-1)^n \vec{w}'] \vec{R}_{\vec{K}} - (-1)^{s_n+n} \vec{w}\vec{w}' G_{\vec{K}} \tag{13}$$

where:

$$D_{\vec{K}} = \frac{1}{4V} \int_{(V)} \frac{E(\vec{r})}{\rho(\vec{r})^3} [\nabla\rho(\vec{r})]^2 e^{-i\vec{K}.\vec{r}} \, dV \ , \ \vec{R}_{\vec{K}} = \frac{1}{2V} \int_{(V)} \frac{E(\vec{r})}{\rho(\vec{r})^2} [\nabla\rho(\vec{r})] e^{-i\vec{K}.\vec{r}} \, dV \ , \ G_{\vec{K}} = \frac{1}{V} \int_{(V)} \frac{E(\vec{r})}{\rho(\vec{r})} e^{-i\vec{K}.\vec{r}} \, dV \, . \tag{14}$$

and expression (10) becomes:

$$\frac{1}{2} \int_{(V)} E(\vec{r}) [\nabla \vec{Q}(\vec{r})]^2 dV = \frac{\hbar}{4} \sum_{\vec{w}} \sum_{\vec{K}} \left\{ \frac{1}{\sqrt{\omega_{\vec{w}}\omega_{\vec{w}+\vec{K}}}} [D_{\vec{K}} + i\vec{K}.\vec{R}_{\vec{K}} + \vec{w}.(\vec{w}+\vec{K})\vec{G}_{\vec{K}}] \hat{b}_{\vec{w}} (\hat{b}_{-\vec{w}-\vec{K}} + \hat{b}^+_{\vec{w}+\vec{K}}) + \right.$$

$$\left. + \frac{1}{\sqrt{\omega_{\vec{w}}\omega_{\vec{w}-\vec{K}}}} [D_{\vec{K}} + i\vec{K}.\vec{R}_{\vec{K}} + \vec{w}.(\vec{w}-\vec{K}) G_{\vec{K}}] \hat{b}^+_{\vec{w}} (\hat{b}_{\vec{w}-\vec{K}} + \hat{b}^+_{-\vec{w}+\vec{K}}) \right\} \, . \tag{15}$$

It is necessary to substitute integrals (9) and (15) to the expression for Hamiltonian (5). After simplifying it becomes:

$$\hat{H} = \sum_{\vec{w}} \left(\hbar\omega_{\vec{w}} \hat{b}^+_{\vec{w}} \hat{b}_{\vec{w}} + \frac{\hbar\omega_{\vec{w}}}{2} \right) + \frac{1}{2} \sum_{\vec{w}} \sum_{\vec{K}} [V_{\vec{w}+\vec{K}} \hat{b}_{\vec{w}} (\hat{b}_{-\vec{w}-\vec{K}} + \hat{b}^+_{\vec{w}+\vec{K}}) + V_{\vec{w}-\vec{K}} \hat{b}^+_{\vec{w}} (\hat{b}_{\vec{w}-\vec{K}} + \hat{b}^+_{-\vec{w}+\vec{K}})] +$$

$$+ \frac{1}{2} \sum_{\vec{w}} \sum_{\vec{K}} [V^*_{\vec{w}+\vec{K}} \hat{b}^+_{\vec{w}} (\hat{b}_{-\vec{w}-\vec{K}} + \hat{b}_{\vec{w}+\vec{K}}) + V^*_{\vec{w}-\vec{K}} \hat{b}_{\vec{w}} (\hat{b}^+_{\vec{w}-\vec{K}} + \hat{b}_{-\vec{w}+\vec{K}})] \tag{16}$$

where coefficients $V_{\vec{w}\pm\vec{K}}$ are:

$$V_{\vec{w}\pm\vec{K}} = \frac{\hbar}{4V\sqrt{\omega_{\vec{w}}\omega_{\vec{w}\pm\vec{K}}}} \int_{(V)} \frac{E(\vec{r})}{\rho(\vec{r})} \left[\frac{1}{4} \left(\frac{\nabla\rho(\vec{r})}{\rho(\vec{r})} \right)^2 + \frac{i\vec{K}}{2} \cdot \left(\frac{\nabla\rho(\vec{r})}{\rho(\vec{r})} \right) + \vec{w}.(\vec{w}\pm\vec{K}) \right] e^{-i\vec{K}.\vec{r}} \, dV - \frac{\hbar\omega_{\vec{w}}}{4} \delta_{\vec{K},0} \, . \tag{17}$$

Operator $\hat{H}$ is Hamiltonian of inhomogeneous oscillating ceramic system.

Having obtained $\hat{H}$, we may calculate average value of energy of ceramic oscillating powder system:

$$\langle W \rangle = \langle \psi | \hat{H} | \psi \rangle = \langle W_1 \rangle + \frac{\hbar}{4V} \int_{(V)} \frac{E(\vec{r})}{\rho(\vec{r})} \left[\frac{A}{4} \left(\frac{\nabla\rho(\vec{r})}{\rho(\vec{r})} \right)^2 + \vec{B} \cdot \left(\frac{\nabla\rho(\vec{r})}{\rho(\vec{r})} \right) + C \right] dV \tag{18}$$

where:

$$\langle W_1 \rangle = \mathrm{Re} \sum_{\vec{w}} \frac{\hbar\omega_{\vec{w}}}{4} \langle \psi | \hat{b}_{\vec{w}} \hat{b}^+_{\vec{w}} + \hat{b}^+_{\vec{w}} \hat{b}_{\vec{w}} - \hat{b}_{\vec{w}} \hat{b}_{-\vec{w}} - \hat{b}^+_{\vec{w}} \hat{b}^+_{-\vec{w}} | \psi \rangle \ , \ A = \mathrm{Re} \sum_{\vec{w}} \sum_{\vec{K}} (X_{\vec{w}+\vec{K}} + X_{\vec{w}-\vec{K}}) e^{-i\vec{K}.\vec{r}} \ ,$$

$$\vec{B} = \mathrm{Re} \frac{i}{2} \sum_{\vec{w}} \sum_{\vec{K}} \vec{K} (X_{\vec{w}+\vec{K}} + X_{\vec{w}-\vec{K}}) e^{-i\vec{K}.\vec{r}} \ ; \ C = \mathrm{Re} \sum_{\vec{w}} \sum_{\vec{K}} [\vec{w}.(\vec{w}+\vec{K}) X_{\vec{w}+\vec{K}} + \vec{w}.(\vec{w}-\vec{K}) X_{\vec{w}-\vec{K}}) e^{-i\vec{K}.\vec{r}} \tag{19}$$

and coefficients:

$$X_{\vec{w}+\vec{K}} = \frac{\hbar}{\sqrt{\omega_{\vec{w}}\omega_{\vec{w}+\vec{K}}}} \langle \psi | \hat{b}_{\vec{w}} (\hat{b}_{-\vec{w}-\vec{K}} + \hat{b}^+_{\vec{w}+\vec{K}}) | \psi \rangle \ ; \ X_{\vec{w}-\vec{K}} = \frac{\hbar}{\sqrt{\omega_{\vec{w}}\omega_{\vec{w}-\vec{K}}}} \langle \psi | \hat{b}^+_{\vec{w}} (\hat{b}_{\vec{w}-\vec{K}} + \hat{b}^+_{-\vec{w}+\vec{K}}) | \psi \rangle \tag{20}$$

ψ is wave function of oscillating system.

DISCUSSION

The experimental results and theoretical analysis of energy transport across the powder have shown that five topical questions, which can be discussed are follows:

a) Considered spatial changes of $\rho(\vec{r})$ and $E(\vec{r})$ in the powder have no influence on fundamental commutator relationship (4) between operators $\hat{b}_{\vec{w}}$ and $\hat{b}^+_{\vec{w}}$. Consequently, $\hat{b}_{\vec{w}}$ and $\hat{b}^+_{\vec{w}}$ in formula (16) represent creation and annihilation operators of acoustic phonons with wave vector $\vec{w}$ inside the powder.

b) From result (16) it can be seen that process of propagation of acoustical waves across inhomogeneous sample is joined with spontaneous emission ($\hat{b}^+_{\vec{w}}\,\hat{b}^+_{-\vec{w}}$, $\hat{b}^+_{\vec{w}}\,\hat{b}^+_{-\vec{w}+\vec{K}}$) and absorption ($\hat{b}_{\vec{w}}\hat{b}_{-\vec{w}}$, $\hat{b}_{\vec{w}}\hat{b}_{-\vec{w}-\vec{K}}$) of phonons. There are the processes, which are qualitatively different from induced emission and absorption of phonons and consequently this can be one of reason for anomalies of acoustical properties of powders.

c) Taking into account the above mentioned results, we can write Schrödinger equation, which describes stationary process of propagation of acoustic waves across the powder as:

$$(\hat{H}_0+\hat{H}_1)\psi = E\psi \tag{21}$$

where:

$$\hat{H}_0 = \sum_{\vec{w}} \hbar\omega_{\vec{w}}\hat{b}^+_{\vec{w}}\hat{b}_{\vec{w}} \tag{22}$$

and operator:

$$\hat{H}_1 = \frac{1}{2}\sum_{\vec{w}}\sum_{\vec{K}}[V_{\vec{w}+\vec{K}}\hat{b}_{\vec{w}}(\hat{b}_{-\vec{w}-\vec{K}}+\hat{b}^+_{\vec{w}+\vec{K}}) +$$
$$+ V_{\vec{w}-\vec{K}}\hat{b}^+_{\vec{w}}\;(\hat{b}_{\vec{w}-\vec{K}}+\hat{b}^+_{-\vec{w}+\vec{K}}) + V^*_{\vec{w}+\vec{K}}\hat{b}^+_{\vec{w}}(\hat{b}^*_{-\vec{w}-\vec{K}}+\hat{b}_{\vec{w}+\vec{K}}) +$$
$$+ V^*_{\vec{w}-\vec{K}}\hat{b}_{\vec{w}}(\hat{b}^+_{\vec{w}-\vec{K}}+\hat{b}_{-\vec{w}+\vec{K}})] \tag{23}$$

is generated by inhomogeneities caused by mentioned inequable particles distribution inside the powder. E is energy of the oscillating system. It is apparent, that in the case of "ideal homogeneous" system (equable particles distribution in the powder) operator $\hat{H}_1$ is vanishing and Hamiltonian (16) is reduced to well known form (22).

d) As it can be shown from (18), internal forces are generated during the sound wave propagation inside the powder system as a consequence of inhomogeneous distribution of particles. The spatial density of mentioned internal forces can be given by:

$$\langle\vec{\chi}\rangle = -\nabla\langle w_0\rangle = \sum_{\vec{K}} U_{\vec{K}}(\vec{r})\vec{K} +$$
$$+\left(\sum_{\vec{K}} M_{\vec{K}}(\vec{r})\vec{K}\right)\cdot\nabla\left(\frac{\nabla\rho(\vec{r})}{\rho(\vec{r})}\right)+$$
$$+\; R(\vec{r})\nabla\left[\frac{E(\vec{r})}{\rho(\vec{r})}\left(\frac{\nabla\rho(\vec{r})}{\rho(\vec{r})}\right)^2\right] \tag{24}$$

where:

$$U(\vec{r}) = -\mathrm{Re}\sum_{\vec{w}}\frac{\hbar}{4V}\left\{i\,\frac{E(\vec{r})}{4\rho(\vec{r})}\left(\frac{\nabla\rho(\vec{r})}{\rho(\vec{r})}\right)^2 X_{\vec{w},\vec{K}} +\right.$$
$$\left.+\frac{1}{2}\frac{E(\vec{r})}{\rho(\vec{r})^2}(\vec{K}.\nabla\rho(\vec{r}))X_{\vec{w},\vec{K}} + i\,\frac{E(\vec{r})}{\rho(\vec{r})}Z_{\vec{w},\vec{K}}\right\}$$

$$M_{\vec{K}}(\vec{r}) = -\mathrm{Re}\frac{i\hbar}{8V}\sum_{\vec{w}}X_{\vec{w},\vec{K}}\;;\; R(\vec{r}) = -\mathrm{Re}\,\frac{\hbar}{16V}\sum_{\vec{w}}\sum_{\vec{K}}X_{\vec{w},\vec{K}}$$

and constants:

$$X_{\vec{w},\vec{K}} = (X_{\vec{w}+\vec{K}}+X_{\vec{w}-\vec{K}})e^{-i\vec{K}.\vec{r}}\;;$$

$$Z_{\vec{w},\vec{K}} = [\vec{w}.(\vec{w}+\vec{K})X_{\vec{w}+\vec{K}}+\vec{w}.(\vec{w}-\vec{K})X_{\vec{w}-\vec{K}})e^{-i\vec{K}.\vec{r}}$$

$\Delta w_0\rangle$ in formula (24) is contribution of spatial density of the energy generated inside the powder as a consequence of inhomogeneities caused by inequable particles distribution in powder volume. As it can be seen from equation:

$$\langle W\rangle = \langle W_1\rangle + \int_{(V)}\langle w_0\rangle dV$$

mentioned contribution can be derived from (18). It can be given by:

$$\langle w_0\rangle = \frac{\hbar}{4V}\left\{\frac{E(\vec{r})}{\rho(\vec{r})}\left[\frac{A}{4}\left(\frac{\nabla\rho(\vec{r})}{\rho(\vec{r})}\right)^2 +\right.\right.$$
$$\left.\left.+\,\vec{B}\cdot\left(\frac{\nabla\rho(\vec{r})}{\rho(\vec{r})}\right)+C\right]\right\} \tag{25}$$

We suggest, that internal forces with spatial density (24) generate all changes in the powder volume during the sound wave propagation inside the powder. The actual particles and "holes" distributions in the powder are included in formulas (24) and (25) by means of both the local average powder mass density value $\rho(\vec{r})$ and local value of $E(\vec{r})$.

e) The experimental results agree with presented theoretical considerations. Frequency dependence of angular distribution functions of 002 reflection intensity was observed. Significant peak was apparently detected only in the case of frequency 500 Hz. Acoustical waves propagation of both lower and higher frequencies then

500 Hz did not generate the quasi-orientation process of particles inside the powder. It can be concluded on the basis of measured results, that frequency 500 Hz is most close to "optimal" frequency shown in figure 3.

CONCLUSION

It can be concluded on the basis of performed analysis, that quasi-orientation process inside the powder is created if the conditions are suitable. Gradual quasi-orientation process of particles basal planes to the horizontal level can be expected during sound waves of "optimal" frequency propagation inside the powder. The powder must be placed in the gravitational field for that reason, too.

It can be expected, that vertical orientation of *c*-axis (angle 0°) is preferred in the case of a "optimal" frequency ω_0. Notice, the presented theoretical (continual) model shown in figure 5 is suitable only under two conditions, the wavelengths of acoustical waves are too large in comparison with sizes of powder particles and the coupling mechanism can intermediate the transport of energy in considered form.

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AKUSTICKÉ EXCITÁCIE $YBa_2Cu_3O_{7-x}$ PRÁŠKOV V GRAVITAČOM POLI

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Anizotropia fyzikálnych vlastností je jednou zo základných charakteristík keramických materiálov založených na báze oxidov medi, ktorá vyplýva z chrakteru ich štruktúry [1-15]. U spekaných materiálov $YBa_2Cu_3O_{7-x}$ pripravených tepelným spracovaním zlisovaného prášku uvedená anizotropia zaniká. Anizotropia fyzikálnych vlastností jednotlivých častíc prášku, ktorá je obvykle spojená s ich tvarovou anizotropiou (obr.1), sa v procese prípravy finálneho materiálu ruší v dôsledku rôznej orientácie častíc v prášku (obr.6).

Rovnaké množstvá prášku $YBa_2Cu_3O_{7-x}$ boli vystavené transportu akustických vĺn rôznych frekvencií a následne zlisované tlakom 150 MPa. Takto pripravené vzorky boli podrobené RTG analýze. Na základe intenít reflexií od difrakčných rovín [002] zosnímaných v okolí vzoriek boli zostrojené distribučné funkcie charakterizujúce rozdelenie častíc zlisovaného prášku podľa ich priestorovej orientácie (obr.2 - obr.4). V prípade transportu akustických vĺn s frekvenciou 500 Hz vykazuje príslušná distribučná funkcia maximum v okolí -6°, čo nasvedčuje zorientovaniu veľkého množstva častíc približne do horizontálneho smeru (obr.3a, obr.3b).

Bola uskutočnená teoretická analýza transportu akustických vĺn cez prášok. Závery vyplývajúce z teoretického modelu sú v súlade s experimentálnymi výsledkami. Na základe uskutočnenej analýzy možno vysloviť záver, že pri transporte zvuku cez prášok $YBa_2Cu_3O_{7-x}$ sú za určitých predpokladov vhodné podmienky pre zorientovanie veľkého množstva častíc prášku približne do horizontálneho smeru (obr.7). Prášok musí byť umiestnený v gravitačnom poli.

Uvedený proces akustických excitácií práškov v gravitačnom poli umožňuje za určitých predpokladov definovať preferovaný smer orientácie niektorej z kryštalografických osí častíc prášku za účelom prípravy orientovaného spekaného materiálu s význačnými vlastnosťami v danom smere.