NONLINEAR DIELECTRIC RESPONSE OF MICROCOMPOSITE DISPLACIVE FERROELECTRICS.

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Abstract

A dielectric nonlinear response in model two-phase composites, prepared from a displacive ferroelectric material with a dominant dielectric response due to a single oscillator ferroelectric mode and a dielectric material, is characterized by the existence of new modes due to geometric resonances below the percolation threshold in the ferroelectric matrix. The geometric nature of oscilations depends on composition and geometric properties of the mixture. Generation of higher frequency modes is studied within our model and discussed for displacive ferroelectric materials of the $BaTiO_3$ type. The Bergman Representation of the effective dielectric function together with our model for spectral function recently introduced are used simultaneously with theory of absorption in finite displacive ferroelectric crystals in quasistatic approximation to describe the physics of the composite. The boundaries of the present study are within this quasistatic approximation. New ways how to optimize material properties for nonlinear optics is outlined.

Contents

1 Introduction.

Dielectric response of ferroelectric microcomposite materials formed from order-disorder ferroelectric and dielectric grains as components have been shown recently [1] to display features not present in pure order-disorder ferroelectrics nor in pure dielectrics. Finite size effects of grains (depolarization effects and intergrain interactions) may lead to new effective properties of the resulting medium. Different effective medium theories (Maxwell-Garnet Theory, the Effective Medium Approximation theory and the Bergman Representation of the effective dielectric function) were used in [1] together with the theory of absorption in finite ferroelectric crystals in quasistatic approximation to describe the physics of the composite. One of main results concerned existence of a relaxation mode due to geometric resonances which lead to new absorption peak below the percolation threshold in the ferroelectric matrix. The soft mode still exists in this matrix too, with renormalized mode strength and unchanged relaxation frequency. Another feature found is hardening of the soft mode in the dielectric phase in which finite ferroelectric clusters exist. High-frequency dielectric function is also modified in a nonlinear way as concerning the concentration dependence of ferroelectric particles. It is the aim of this paper to study dielectric response in ferroelectric microcomposites in which the ferroelectric component is of the displacive type instead of the order-disorder type, and the dominant response of which to electric field is due to an oscillator type polar mode. Thus this our study represent extension of our previous one concerning order-disorder type materials [1], to a more general class of materials with oscillator type of mode. Note that the order-disorder type characteristics are limiting case of the oscillator type for larger values of the damping constant. A still more realistic model should be based on the multimode approach, however, the single mode case, as adopted here, gives main qualitative features of the new characteristics present in the microcomposite. It corresponds to the multimode case in which the soft mode is sufficiently softened below other resonance modes in the lower frequency region. All but the soft mode are semiempirically taken into account in our approach via the high-frequency dielectric constant. To clarify which relaxation processes are present in such composites we use the Bergman Representation for the effective dielectric function together with our model for the spectral function introduced in [1]. This choice is supported by the fact, that the mentioned representation covers the whole spectrum of the particle concentrations, reflects existence of the percolation transition and that our model spectral function gives in the limiting cases of small concentrations results which are identical in the main order with those obtained by using the Maxwell-Garnet Theory. It is well known that the Maxwell-Garnet Theory is appropriate and sufficiently simple to identify qualitative changes of the composite properties at small concentration limits of one of the components only. The Bergman Representation is useful for discussions of the dynamic properties of the effective dielectric function, which go beyond results obtained within the frame of the other known theories. First the model of two-phase microcomposite ferroelectric medium is introduced in which the ferroelectric part consists of the displacive material. We start with some results following from theory of absorption in finite displacive ferroelectric crystals in quasistatic approximation. One of the main results of this paper consists of confirmation of presence of the new relaxation mode due to geometric resonance also in displacive type

ferroelectric microcomposites. Another feature discussed in this paper is hardening of the soft mode in the phase with infinite dielectric matrix in which finite ferroelectric clusters exist. Below the percolation threshold the soft mode exists with renormalized mode strength. High-frequency dielectric function is also modified resulting in a nonlinear dependence on concentration of ferroelectric particles. Spontaneous birefringence of ferroelectric materials usually depends linearly or quadratically in spontaneous polarization depending on the character of the paraelectric phase. In the last section a nonlinear susceptibility of microcomposite displacive ferroelectrics is calculated.

2 Model of two-phase microcomposite displacive ferroelectric medium.

Model microcomposite displacive ferroelectric materials are considered here to be those materials which are composed from two phases: a normal dielectric material, and a ferroelectric material undergoing in bulk at some temperature a second order displacive phase transition from paraphase to ferroelectric phase. For simplicity we assume that our model microcomposite consists of packed spherical particles. We assume that the interparticle free volume due to random packing of spheres is semiempirically taken into account in our calculations of effective dielectric properties of the composite due to properties of the Bergmann Representation spectral function, see in [1], [2] and [3]. Let our composite be based on two basic materials. One of them is a displacive ferroelectric material (F). Let its relative volume concentration be $(1 - x)$, where x is the volume concentration of dielectric grains: $0 \leq x \leq 1$. Let us further assume that the soft mode behavior of the bulk is conserved in the material from which spherical ferroelectric particles are formed, we assume that these particles are sufficiently large. There are, however, corresponding size and shape modification of the dielectric response of such grains, the soft mode behavior of particles is assumption which is based on corresponding results of our recent calculations [4] concerning dynamic dielectric response of small ferroelectric particles. A contribution to the total effective permittivity due to contribution ε_F of the ferroelectric F grains is at lower frequencies in good approximation described by a single oscillator process characteristic for displacive type systems:

$$\varepsilon = \triangle\varepsilon + \varepsilon_\infty \tag{1}$$

where:

$$\triangle\varepsilon = \frac{f}{\omega_0^2 - \omega^2 + i.\omega.\Gamma},$$

ε_∞ is high-frequency dispersions mechanisms contribution, Γ is the inverse relaxation time, ω is frequency and ω_0 is the soft mode resonance frequency. Note that in the case of order-disorder ferroelectrics one correspondingly considers the limit of an overdamped oscillator. We assume that the ferroelectric (F) material is characterized in bulk by a single second order phase transition critical temperature T_C. Contributions of other hard modes present in the bulk material to the dynamic dielectric function ε_F of the pure ferroelectrics F are included approximately in the high-frequency contribution ε_∞. We consider those lower frequencies at which the soft mode contribution dominates the response. The

oscillator strength f, the soft mode frequency ω_0 and the inverse relaxation time Γ in this material are temperature dependent quantities in general. The soft mode is softening at the center of the Brillouin zone:

$$\omega_0 = \omega_{0,HT}.a^{-1}. \mid 1 - \frac{T_C}{T} \mid . \tag{2}$$

The numerical constant a takes the following values: $a = 1$ above the transition temperature T_C, and $a = \frac{1}{2}$ below that temperature, in correspondence with the Landau theory [5] of such phase transitions. It is, however, convenient to neglect weak temperature dependence of the oscillator strength f and of the inverse relaxation time and to consider both quantities as material constants. This assumption is in general not correct: there is certainly some temperature dependence of the single-atomic relaxation modes. We assume that this assumption is valid near the transition temperature. As concerning particle diameter d a distribution of diameters should exist there in real systems with some average diameter and with some characteristic variance of diameters. In correspondence with existing methods of grains preparation we again assume that the variance of diameters is negligible and that its value in our model composite is the same for the whole range of concentrations x. Let us note that for very large diameters d the paraelectric-ferroelectric phase transition may be well described by the formula (2) in which neither critical temperature T_C nor material constants are size dependent. For smaller values of the diameter d the critical temperature T_C and the material constants are quantities dependent on the diameter d, as it was recently discussed in [4]. Moreover, we assume that there is no dispersion of the transition temperatures in ferroelectric grains. The other basic material from which our ferroelectric composite medium is composed is a dielectric material (D). We assume that its permittivity is in considered temperature and frequency region in good approximation described by a constant real dielectric function ε_D :

$$\varepsilon_D \approx const. \tag{3}$$

The volume concentration of macroscopic domains, formed from grains containing the dielectric D is x. To perform orientational numerical estimates one may use such numerical values of material constants occurring in our model system, which are characteristic [6] for displacive ferroelectric materials of the $BaTiO_3$ type: $T_C = 391 \ K$, the Curie constant $C = 1.7 \ 10^5 \ K$, the high temperature inverse time $\frac{\Gamma}{\omega_{0,HT}^2.a^{-1}} = 10^{13} \ s$, and $\varepsilon_\infty = 5$. Note that the Curie constant C is related to the oscillator strength via the relation $C = \frac{f}{\omega_{0,HT}^2.a^{-1}}$. The high temperature limiting frequency $\omega_{0,HT}$ need not to be specified if the frequency ω is measured in units of $\omega_{0,HT}$. The permitivity of the dielectric grains is considered to be the same as in the bulk dielectric material, which gives a typical value $\varepsilon_D = 10$.

A starting point in our calculations is to consider dielectric response of a finite-size ferroelectric grain in a dielectric medium. Differences in dielectric functions between two materials, finite size and depolarization field effects lead to a dielectric response which is different from that of a bulk ferroelectric material. When concentration of grains increases then the electric field which is external to a given grain is modified due to other grains. Thus multiplication effects due to mutual influence of many grains in a given medium may lead to new phenomena as concerning the dielectric response of such a system. The general

approach to the description of the effective medium is based on the Bergmann Representation of the effective dielectric constant. This approach is used in our last section but one using a simple model spectral density function, the limiting cases of which lead to the Maxwell-Garnett Theory and which simultaneously describes well the percolation transition in a very transparent form.

3 Theory of absorption in finite displacive type ferroelectric crystals in quasistatic approximation.

A ferroelectric displacive type ellipsoidal sample inserted in a medium with dielectric constant ε_D responses to a homogeneous external electric field $\mathbf{E}_M$. A resulting electric field $\mathbf{E}$ in the quasistatic approximation is homogeneous too, and is equal to, [7]:

$$\mathbf{E} = \frac{\varepsilon_D.\mathbf{E}_M - \gamma.\mathbf{D}}{\varepsilon_D.(1 - \gamma)}, \tag{4}$$

where the depolarization field is given by:

$$\mathbf{E}_{dep} = 4.\pi.\gamma.\frac{\varepsilon - \varepsilon_D}{\varepsilon_D.(\varepsilon - 1)}.\mathbf{P}.$$

Here ε is a dielectric function of the sample, γ is a depolarization factor of the grain for which $0 \leq \gamma \leq 1$. Note that spherical shape of isotropic grains represents the most simplified version of grains shape description. It will be used here, thus the depolarization factor is $\gamma = \frac{1}{3}$. It is convenient to introduce the effective dielectric constant ε^* as a change of the electric induction field due to a change of the electric field in zero external field $\mathbf{E}_M$ instead of a dielectric constant ε as change of the electric induction field due to the change of the electric field $\mathbf{E}$ in zero field limit. Then we obtain:

$$\varepsilon^* = \frac{\varepsilon.\varepsilon_D}{\varepsilon_D.(1 - \gamma) + \gamma.\varepsilon} \tag{5}$$

After substitution of the soft mode behavior for the ferroelectric material (1) we obtain:

$$\varepsilon^* = \triangle\varepsilon^* + \varepsilon_\infty^*. \tag{6}$$

where

$$\triangle\varepsilon^* = \frac{f^*}{\omega_0^{*2} - \omega^2 + i.\omega.\Gamma}.$$

The renormalized soft mode strength f^* is given by:

$$f^* = f.\frac{\varepsilon_D^2.(1 - \gamma)}{[\varepsilon_D.(1 - \gamma) + \gamma.\varepsilon_\infty]^2}, \tag{7}$$

and the renormalized (former soft, now hard) mode frequency behavior is:

$$\omega_0^{*2} = \omega_0^2 + \frac{f.\gamma}{\varepsilon_M.(1 - \gamma) + \gamma.\varepsilon_\infty}. \tag{8}$$

The inverse relaxation time Γ is found to be unchanged in this grain. The frequency behavior of ε^* is qualitatively the same as that of ε. Quantitatively

both quantities are not the same, the oscillator strength is decreased ($f^* < f$), and the mode frequency is substantially increased ($\omega_0^{*2} >> \omega_0^2$). Moreover the high-frequency dispersions mechanisms contribution ε_∞ changes to ε_∞^* :

$$\varepsilon_\infty^* = \frac{\varepsilon_\infty . \varepsilon_D}{\varepsilon_D . (1 - \gamma) + \gamma . \varepsilon_\infty}. \tag{9}$$

The high frequency contributions are also renormalized and the high-frequency dielectric function is smaller for dielectric medium with dielectric constant smaller than the original high-frequency constant of the pure ferroelectric material, and vice versa. Results of this section concern the single ferroelectric crystallite in a dielectric homogeneous medium. The composite material corresponds with this situation in the limit of very small concentration of ferroelectric crystallites with very large intergrain distances. Increasing concentration of crystallites their distance decreases and the electric field acting on a given crystallite becomes modified due to presence of other crystallites. Consequently the effective dielectric response changes from that described above. To describe corresponding modifications we have to include not only effects of a finite crystallite dimensions but also a finite intergrain distances effects via concentration effects. We consider such effects in next sections. To discuss the whole concentration range we need to consider not only the situation in which dielectric medium contains ferroelectric particles but also the inverted one in which ferroelectric matrix contains small dielectric particles.

4   Bergmann Representation of the effective dielectric function.

A two-phase composite with sharp boundaries between two phases has been shown [3] to be represented in general (in the quasistatic approximation) as a sum of simple poles. The weight of each pole is given by the specific spectral density function characterizing the geometry of a given composite and of a topology of clusters formed from particles of a given type. Such a representation is known as the Bergman Representation [3]. Introducing abbreviation $t \equiv \frac{\varepsilon_D}{\varepsilon_D - \varepsilon}$ one finds that the effective dielectric function of the composite has in the Bergman Representation the form:

$$\varepsilon_{eff} = \varepsilon_D . (1 - (1 - \gamma) \int_0^1 \frac{g(n, x)}{t - n} . dn). \tag{10}$$

Here $g(n, x)$ is the spectral density function containing all information about geometry and other properties of the composite. It is possible to show, using formulas from [3], that the zeroth and the first order moments of the spectral density function $g(n, x)$ are given by:

$$\int_0^1 g(n, x) . dn = 1 \tag{11}$$

which is a normalization condition, and by:

$$\int_0^1 n . g(n, x) . dn = \frac{x}{3}. \tag{12}$$

The zeroth moment is found to hold for general conditions, but the first moment has the form (12) only in the case of statistical isotropy [3], which is assumed to be present in our composite further in our paper. Using our model parametrization of the permittivity of dielectric particles and of the ferroelectric particles, see (1), the effective permittivity in the Bergman Representation takes the form:

$$\varepsilon_{eff} = \varepsilon_D - \varepsilon_D.(1-x).\int_0^1 \frac{\varepsilon_D - \varepsilon_\infty}{\varepsilon_D.(1-n) + \varepsilon_\infty.n}.g(n,x).dn + \quad (13)$$

$$+\varepsilon_D.(1-x).\int_0^1 \frac{\Phi^*(n)}{\omega_0^{*2} - \omega^2 + i.\omega.\Gamma}.g(n,x).dn.$$

The first two terms describe the modified dielectric high-frequency response and the last term represents a sum of contributions due to oscillator processes generated by the microcomposite, each process corresponding to a specific value of the parameter n. It contributes with the modified strength $\Phi^*(n)$, the weight $g(n,x)$, and the resonance frequency $\omega_0^*(n)$, where:

$$\Phi^*(n) = \frac{f.\varepsilon_D}{(\varepsilon_D(1-n) + \varepsilon_\infty.n)} \quad (14)$$

and where:

$$\omega_0^{*2}(n) = \omega_0^2 + \frac{f.n}{\varepsilon_D.(1-n) + \varepsilon_\infty.n}. \quad (15)$$

Dependence on the geometric and topological factors is fully contained in the spectral density function $g(n,x)$. From (14) and (15) we see that the $n = 0$ mode contributes with the same frequency as the original ferroelectric mode, its strength is weighted by $(1-x).g(0,x)$. Parameterization of the spectral density, corresponding to our model ferroelectric composite will be in our paper based on the same assumptions as in our recent paper [1]. There are in general two main contributions in composites to the spectral function, [2], a peak between $n = 0.2$ and $n = 0.3$ assigned to geometrical resonances of finite clusters and isolated particles, and a steep delta-like contribution at $n = 0$ assigned to the resonances of an infinite percolating cluster. As a simplification we will demand in our paper that at small concentrations of dielectric particles the Maxwell-Garnett Approach approximation should result and at large concentrations $(x \approx 1)$ the Maxwell-Garnett Theory approximation should be valid for description of a dielectric matrix containing ferroelectric particles. These our assumptions about the spectral function can be easily satisfied assuming the following two-peak form of the spectral density [1]:

$$g(n,x) = g_0(x).\delta(n) + a(x).\delta(n - n_T(x)). \quad (16)$$

In (16) the first delta peak is localized at $n = 0$, in correspondence with general expectations [2], and $g_0(x)$ describes its relative intensity for a given composite concentration x. This peak is due to an infinite ferroelectric cluster contribution, if this type of cluster is present in the composite. The second delta peak in (16) is localized at some nonzero value of the parameter $n = n_T(x)$, here $a(x)$ describes the relative intensity of this peak. While the second peak is expected on the general grounds to be of the wide shape, here in our model its shape is very

narrow. The localization of the second peak is here assumed to be dependent on the concentration x of the dielectric particles:

$$n_T(x) = \frac{x}{3} \tag{17}$$

for x above the percolation threshold, which was already determined in the previous section at the critical concentration $x_C = \frac{2}{3}$. In this region an infinite dielectric cluster is present and there are finite ferroelectric and other dielectric clusters. The concentration dependence of this contribution due to geometric resonances reflects the Maxwell-Garnett Theory type of the effective medium behavior of finite clusters forming some kind of a dipolar medium. Below the percolation concentration we assume that the geometric resonances due to remaining finite ferroelectric and dielectric clusters are present simultaneously with infinite ferroelectric cluster. This region is characterized by a concentration independent position $n_T = \frac{2}{9}$ of the corresponding peak in the spectral density function. For concentrations below the critical concentration both relative intensities have the following form [1]:

$$g_0(x) = \frac{x_C - x}{x_C}, \tag{18}$$

$$a(x) = \frac{x}{x_C}.$$

In this region the weight $a(x)$ decreases from the value 1 (for $x = 0$)to the value 0 (for $x = x_C$). The weight $g_0(x)$ decreases here from the value 1 (for $x = 0$) to the value 0 (for $x = x_C$). Note that the sum of weights is one: $a(x) + g_0(x) = 1$. Above the percolation transition we assume the constant concentration independent form of the densities $g_0(x) = 0$ and $a(x) = 1$. Note that the spectral density function (16) satisfies the zeroth moment and first moment conditions in the whole range of concentrations x. One should note that a broader peak in the spectral density function would lead to many other oscillator-like resonance terms in the effective dielectric function describing a distribution of geometric resonance frequencies. Such a picture would be more acceptable on the intuitive base. Here we consider a simple case of a single (effective) geometric resonance. Our model approach, however, still contains essential features of the realistic response function and represents some extension of the theory behind the Maxwell-Garnet Theory as well as behind the Effective Medium Approach. In this way we succeeded to formulate physically more acceptable model response function for the ferroelectric composite which is still sufficiently clear in its structure. Substituting our spectral density function from (16) to the expression for the effective dielectric response function (10) we obtain:

$$\varepsilon_{eff} = \varepsilon_D - (1-x).g_0(x)(\varepsilon_D - \varepsilon\infty) - \tag{19}$$

$$-(1-x).\varepsilon_D.a(x).\frac{\varepsilon_D - \varepsilon\infty}{\varepsilon_D.(1-n_T) + \varepsilon_\infty.n_T} +$$

$$+(1-x).g_0(x).\frac{\varepsilon_0 - \varepsilon_\infty}{\omega_0^2 - \omega^2 + i.\omega.\Gamma} +$$

$$+\varepsilon_D.(1-x).a(x).\frac{g^*(n_T)}{\omega_0^{*2}(n_T) - \omega^2 + i.\omega.\Gamma}.$$

The first three terms describe modified high-frequency response, the last two terms describe frequency response in the form of two simple resonances. The last but one term corresponds to the response of an infinite ferroelectric cluster below the percolation threshold. The ferroelectric displacive-type infinite cluster responses in the same way as it is assumed to be present in pure bulk ferroelectric material. However, its relative intensity is decreased by the factor $(1-x)g_0(x)$ and vanishes at and above the percolation threshold. The last term describes a response of small finite clusters and isolated particles in the whole concentration range. This response process vanishes at concentration $x = 0$, where a pure ferroelectric matrix is present, and at concentration $x = 1$, where a pure dielectric matrix is present. In both limits there are present no additional contributions due to dipolar properties of the medium. The strength of finite clusters response is given by $\varepsilon_D.(1-x).a(x)\Phi^*(n_T)$. Their frequency is in the form similar to that of a finite particle from (8), in which however instead of the depolarization factor γ the factor n_T is substituted. It is easy to show that the new resonance frequency is always hard, it is not corresponding to the soft mode. At the ferroelectric phase transition temperature this relaxation frequency remains nonzero, it does not completely softens. The relative strength of both relaxation processes below the percolation transition changes. There may exist, however, region in space of physical parameters (concentration, high-frequency permittivities, Curie constant etc.) in which both contributions become comparable.

5   Nonlinear susceptibility of microcomposite displacive ferroelectrics.

Spontaneous birefringence of ferroelectric materials usually depends linearly or quadratically on spontaneous polarization depending on the character of the paraelectric phase [8]. We consider here the $BaTiO_3$ type of materials, for which the paraelectric phase is centrosymmetric and thus the quadratic dependence occurs. Nonlinear coefficients d_{ijl} in this material are linearly dependent on the spontaneous polarization. Nonlinear polarization $\mathbf{P}_{NL}$ is defined by:

$$P_{NL,i}(\omega_1 \pm \omega_2) = \sum_{jk} d_{ijk}.E_j(\omega_1).E_k(\omega_2). \tag{20}$$

Here $d_{ijk}(2.\omega)$ are coefficients ($i, j, k, ..$ denote axises) at doubled frequency ω and are defined by:

$$d_{ijk} = \sum_{lmn} \chi_{il}^L(2.\omega).\chi_{jm}^L(\omega).\chi_{kn}^L(\omega).\delta_{lmn}(2.\omega). \tag{21}$$

Here L is the index for the linear susceptibility. The sign $+$ or $-$ in the relation (21) above depends on the character of the process. As in [8] dispersion of the coefficients δ_{lmn} is assumed to be small.

Assuming an isotropic approximation for the composite susceptibility (which is related to the the effective dielectric response function described above) we obtain:

$$\chi_{il}^L = \delta_{il}\chi_{comp}, \tag{22}$$

where χ_{comp} is the composite dielectric susceptibility in an isotropic medium approximation, and δ_{il} is the Kronecker delta. Studying the longitudinal polarization, we obtain for the nonlinear polarization $P_{NL,i}$:

$$P_{NL,i}(\omega_1 \pm \omega_2) = \sum_{ijk} .d_{ijk} E_j(\omega_1).E_k(\omega_2), \tag{23}$$

where here d_{ijk} coefficients for $\omega_1 = \omega_2 = \omega$ is $d_{ijk}(2.\omega)$:

$$d_{ijk}(2.\omega) = \chi^2_{comp}(\omega).\chi_{comp}(2.\omega)\delta_{ijk}(2.\omega). \tag{24}$$

Here (*comp*) is the index for the composite susceptibility. Second harmonic generation is thus described by nonlinear longitudinal (*l*) polarization $P_{NL,l}$ as:

$$P_{NL,l} = \delta_{lll} E_l^2(\omega).\chi^2_{comp}(\omega.\chi_{comp}(2.\omega). \tag{25}$$

The strength of the new geometric resonance pole and the frequency of the new geometric resonance pole are both temperature and composition dependent quantities. Together with another free parameter, the value of the dielectric constant of the dielectric component, a wide range of microcomposite properties may be prepared depending on the targeted second generation harmonics.

6   Discussion.

In sections above, Introduction, Model of two-phase microcomposite displacive ferroelectric medium, Theory of absorption in finite displacive type ferroelectric crystals in quasistatic approximation, Bergmann Representation of the effective dielectric function and Nonlinear susceptibility of microcomposite displacive ferroelectrics we discussed theory of absorption in finite displacive type ferroelectric crystals in quasistatic approximation two-phase microcomposite displacive ferroelectric medium using the Bergmann representation of the effective dielectric function and nonlinear susceptibility of this microcomposite was calculated.

Let us assume that the above described nonlinear coefficients d_{ijk} are macroscopic quantities averaged over distances much larger than the average fluctuation length of the microcomposite. It is clear that the second harmonic generation in microcomposites due to geometric resonances will display new interesting properties. Changing pure composition concentration, changing chemical composition, eventually introducing the third composite component (theory of which is a little bit more complicated than the theory outlined above) one can obtain a wide diapason of composite properties as concerning the electromagnetic field response. For example optimization of materials with electrooptic properties expected for given device application may be enhanced using nonlinear properties of microcomposites described above.

Acknowledgment

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