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Possible soft-matter quasicrystals of 5- and 10-fold symmetries and hydrodynamics

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ABSTRACT

The dynamics and wave propagation of possible soft-matter quasicrystals with 5- and 10-fold symmetries are studied. Apart from elementary excitations – phonons and phasons, the fluid phonon is introduced in the study for the hydrodynamics of the matter, which was originated from the Landau school. The essential difference of soft-matter quasicrystals with solid quasicrystals lies in the existence of fluid phonon and the interaction between fluid phonon, phonons and phasons. By extending the hydrodynamics theory of solid quasicrystals proposed by Lubensky et al. the hydrodynamics theory of soft-matter quasicrystals is suggested, and we give a numerical implementation through finite difference method. The results in this paper explore some dynamic and wave propagating behaviour of soft-matter quasicrystals with 5- and 10-fold symmetries.

1. Introduction

Soft-matter quasicrystal is a novel and cross discipline subject connecting two subfields of physics and chemistry – soft matter and quasicrystals, and presents important meaning. The soft-matter quasicrystals with 12- and 18-fold symmetries observed in liquid crystals, polymers and colloids etc. [1–5] are quite different from those in solids (including binary and ternary alloys and natural quasicrystals, e.g. [6,7]). In particular, the 18-fold symmetry soft-matter quasicrystals were first discovered. This observation is one of the important events of the 21st century physics and chemistry. The mechanical and physical property study of solid quasicrystals has been achieved a great progress based on the Landau symmetry breaking principle following the pioneering work of Bak [8,9], Lubensky et al. [10–14], etc. How do we study the mechanical and physical properties of soft-matter quasicrystals?

Bak, Lubensky et al. and other pioneers put forward the elementary excitations – phonon and phason and set up the basis of continuum theory of solid quasicrystals. The theory is supported by experiments and has been widely acknowledged. Because soft matter is an intermediate phase between ideal solid and conventional fluid, the other elementary excitation – fluid phonon should be introduced for the study of mechanical properties and relevant physical properties of soft-matter quasicrystals. The concept of fluid phonon was originated from the Landau school [15], they pointed out the fluid acoustic wave is a phonon, the fluid phonon, which presents fundamental importance in condensed matter theory. Fan [16,17] suggested a model for soft-matter quasicrystals based on elementary excitations – phonon, phason and fluid phonon, and derived the equations of motion of the soft-matter quasicrystals. On this basis Fan et al. [18–20] have carried out some work on specific heat and other thermodynamic functions, Stokes–Oseen flow, dislocations and other topics of soft-matter quasicrystals of 12- and 18-fold symmetry observed so far, in which the effects of fluid phonon and interaction between phonon and fluid phonon are explored. However, the decoupling between phonon and phason in soft-matter quasicrystals with 12- and 18-fold symmetries leads unfortunately to lack of response of phason field under the some boundary conditions studied in the work. In this paper we give an analysis for possible soft-matter quasicrystals with 5- and 10-fold symmetries on dynamics and wave propagation, in which the effects of phason and coupling between phason and phonon are explored explicitly. This extends the work on 12- and 18-fold symmetry quasicrystals in soft matter.

2. Equations of motion of soft-matter quasicrystals with 5- and 10-fold symmetries

Soft matter includes liquid crystals (both monomer and polymer liquid crystals), polymers, colloids, foams, surfactants,

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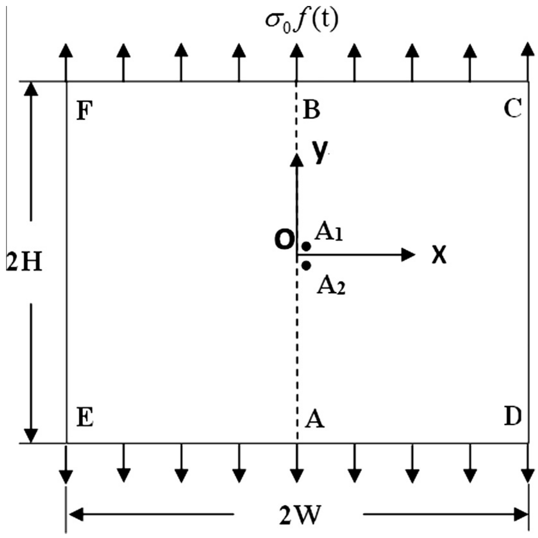

Fig. 1. Specimen of 5- and 10-fold symmetry soft-matter quasicrystals under dynamic loading.

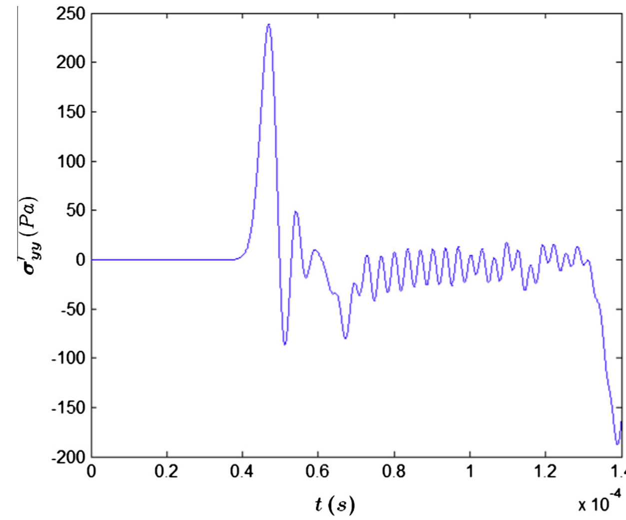

Fig. 3. Fluid normal stress at the point A_1 (or A_2) of specimen versus time.

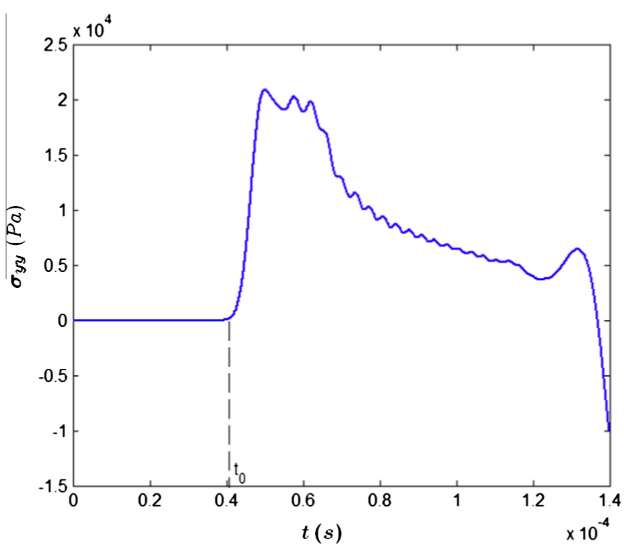

Fig. 2. Elastic normal stress at the point A_1 (or A_2) of specimen versus time.

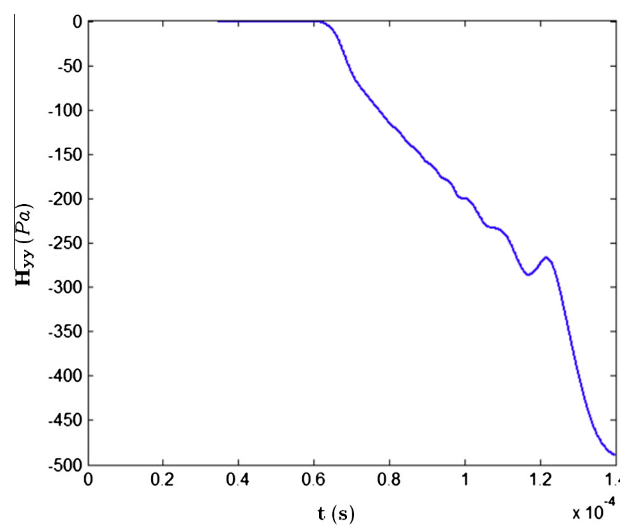

Fig. 4. Phason normal stress at the point A_1 (or A_2) of specimen versus time.

emulsions, biological macromolecules, etc. Between them there are great differences in forms and intra-structures. The attempt to give a universal description on all classes of soft matter is hard to be realized. Among individual classes of the matter, there are some kinds of which, e.g. liquid crystals, the continuum mechanics is well studied comparatively. We can draw the experiences of liquid crystals and solid quasicrystals, and a mathematical model of a class of soft matter [16,17] was suggested. Based on the model and the Poisson bracket method in condensed matter physics [21], the equations of motion for a class of soft matter have been derived as follows

$$\frac{\partial \rho}{\partial t} + div(\rho \mathbf{V}) = 0 \tag{1}$$

$$\rho \frac{\partial V_i}{\partial t} + \rho V_k \frac{\partial V_i}{\partial x_k} = \frac{\partial}{\partial x_j}(\sigma_{ij} + \sigma'_{ij}) \tag{2}$$

$$\frac{\partial s}{\partial t} + div(s\mathbf{V}) = 0 \tag{3}$$

$$\frac{\partial u_i}{\partial t} + V_k \frac{\partial u_i}{\partial x_k} - \Gamma_{\mathbf{u}} \frac{\partial \sigma_{ij}}{\partial x_j} - V_i = 0 \tag{4}$$

in which ρ represents the mass density, $\mathbf{V} = (V_x, V_y, V_z)$ the velocities, or fluid phonon field, according to the Landau theory [15], σ_{ij} the elastic stress tensor, σ'_{ij} the fluid stress tensor, s the entropy, $\mathbf{u} = (u_x, u_y, u_z)$ the displacements of phonons, and $\Gamma_{\mathbf{u}}$ the phonon dissipation kinematic coefficient, respectively. In the following the entropy Eq. (3) will not be used.

It is evident that we have drawn above equations from the work of Lubensky et al. on solid quasicrystals and done some extending.

3. Applications to a class of soft-matter quasicrystals of 5- and 10-fold symmetries

We have mentioned the discovery of soft-matter quasicrystals for a decade, and the mechanical behaviour of the matter has not well been studied so far. The aim of this paper is to use the theory suggested in Section 2 to study possible soft-matter quasicrystals of 5- and 10-fold symmetries especially on their mechanical