**Abstract Title**

# Field theoretical approach to deformation and fracture of solid state media and its applicability to nano/micro systems

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**Introduction**

Dynamics at the micro/nano scale is fundamentally different from that at the macro scale. In the world of macro scale, most forces between objects can be considered as the so-called contact forces. In a nano system where the inter-atomic distance is comparable to the object's dimension, there is no clear boundary between the contact force and field force. In a nano structure where the total number of atoms involved is so small that the assumption of thermal equilibrium is questionable, the application of conventional statistically-based concepts such as diffusion or viscosity becomes uncertain; at least, it is questionable whether the same coefficient as the macro level should be used. Thus the dynamics at the micro/nano level must probably be treated differently from the macro scale.

On the other hand, no comprehensive theory is available for engineers to design micro/nano systems. Consequently, the only option for them is to scale down the design concept used at the macro level. This situation leads to practical problems, such as shortened lifetimes of micro-machines or the measured Young's modulus of a nano material being substantially different from the value of the same material at the macro scale. Considering that manufacturing of macro/nano systems has become a reality, it is the time for us to develop general theories applicable to these scale levels.

**Method**

A possible solution to this problem is to develop a theory on the most fundamental level of physics where scale based approximations become unnecessary. From this viewpoint, a gauge theoretical approach seems to be a powerful method. The basic position of a gauge theory is that it requires that the Lagrangian must possess local symmetry, i.e., the Lagrangian should be invariant under a transformation locally as well as globally. To meet this requirement, it becomes necessary to introduce a compensation field that exerts a force on the physical system. In other words, in compensation for having the freedom to use a coordinate dependent, as oppose to a globally constant, transformation, a new restriction is imposed to the physical system. Then the dynamics can be described as the interaction between the system and the compensation field. A classical example is Maxwell's electrodynamics as a gauge theory; in this view, the electric and magnetic fields are interpreted as compensation fields associated with the locally defined phase transformation of the electric charge's wave function. As the phase transformation of a certain location gains the freedom to be different from other locations, the charge cannot be a free particle any more and can move only under the influence of the electric and magnetic forces. Note that electrodynamics is consistent with

general relativity even at the level where the velocity is close to the speed of light, unlike Newtonian dynamics, which must be modified under that limit.

Physical mesomechanics is a gauge theory applied to the displacement field of plastically deforming solid state media. Panin[1] is the first who systematically developed the basis of this theory. By introducing a finite size to the point mass considered in the conventional continuous mechanics, he discovered the concept of translational-rotational interaction in the deformation field. Egorushkin[2] developed the gauge theoretical formalism for the related dynamics, and successfully derived the field equation that describes the spatio-temporal variation of dislocation density and flow. By combining these two ideas, plastic deformation can be interpreted as an energy relaxation process that obeys a Maxwell type field equation. In this formalism, there is no restriction in the physical size of the finite point, and therefore the formalism should be applicable to any physical scale including the nano scale level.

**Results and discussions**

After summation over the group indices representing different modes of deformation, the above-mentioned field equation takes the same form as Maxwell equation. Indeed, the solution represents a transverse wave analogous to the electromagnetic wave. There are several reports[3,4] on observation of wave characteristics in displacement and strain fields.

Based on the formulaic similarity to electrodynamics, I have been exploring the physical meaning of various formulations derived by physical mesomechanics. Recent development indicates that plasticity can be interpreted as an energy dissipation process analogous to the ohmic loss in electricity, and fracture is analogous to electric breakdown of dielectric media[5]. Thus by identifying equivalence between electricity and plasticity, and making use of the well-developed theoretical basis of electrodynamics, it seems possible to develop a scale insensitive theory of deformation and fracture of solid state media.

The aim of this talk is to introduce my work to the community for critics and questions, and discuss its applicability to nano/micro dynamics.

## Keywords

Deformation, fracture, gauge symmetry

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