REZUMATUL TEZEI DE ABILITARE

In this paper I approached two themes: the study of liquid crystal - ferromagnetic nanoparticles composites and the nonlinear optical phenomena in liquid crystals by highlighting the self-diffraction phenomena. The first chapter is an introductory one, presenting a short review of the main research in the discussed fields.

Chapter 2 contains a brief characterization of nematic liquid crystals (LC) and a description of elastic continuum theory applied to liquid crystals subjected to magnetic field. When mixing LC with ferromagnetic particles (either micro or nano-sized), their properties are considerably different and they are called ferronematics. They were first analysed by Burylov and Raikher who developed an interaction theory between the nematic molecule and ferromagnetic particle's surface. By calculating the composite free energy, and solving the Euler-Lagrange equations, the interaction energy between the LC molecule and ferromagnetic particle's surface can be calculated. The chapter contains a detailed description of the Burylov-Raikher theory on the ferronematics, which was extended on the simple nematic and cholesteric liquid crystals in order to obtain the expression of free energy density in continuum theory for nematic, cholesteric, ferronematic and ferrocholesteric liquid crystals.

A previously oriented liquid crystal, subjected to external fields (electric, magnetic or laser) may change its molecular orientation if the field intensity is higher than a threshold value called the critical field. This phenomena is called the Freedericksz transition. Chapter 3 contains a study of magnetic Freedericksz transition in ferronematics for planar and homeotropic alignment. The experimental set-up and procedure for the measurement of these critical fields is presented followed by experimental data and discussions. The results shown an increase of the ferronematic critical field relative to the pure liquid crystal. This is possible only if the liquid crystal molecules are perpendicularly attached on the surface of the ferroparticles as the theoretical model indicates. Similar procedure is followed when replace the magnetic field with a high intensity laser beam, producing the so-called optical Freedericksz transition.

This chapter, also contains an experimental and theoretical study on the ferronematic and ferrocolesteric transitions due to the external magnetic field and laser radiation.

Thus, the study of Freedericksz transitions in ferronematics subjected to magnetic and laser fields is presented when the electric and magnetic anisotropy of the liquid crystal are both positive, the discussion being made in the case of a strong molecular anchoring on the cell walls. The phase diagram for the transition between the homeotropic aligned ferronematic and the distorted configuration is presented.

Another discussed topic is the surface effects on magnetic Freedericksz transitions in ferronematics. For this, it was considered the anchoring energy f_s on the walls of the liquid crystal cell given by Yang $f_s=(1/2)A\sin^2\theta(1+\xi\sin^2\theta)$ instead of well-known Rapini and Poupular $f_s=(1/2)A\sin^2\theta$. In this formula, f_s not only depends on the interaction surface A, but also on another phenomenological parameter ξ. The study was performed for a homeotropically aligned ferronematic. Using the variational method, a transcendental equation in which only the parameter A appears was obtained. In strong anchoring approximation, the value of the critical field calculated in the previous study is experimentally reached. At the same time, I discussed the conditions to obtain the first and second transition order. Since the nematic anchoring is not usually a rigid one, I also calculated the saturation field, i.e. the field where the alignment of the ferronematic is completely flat. It should be noted that, in this case, a transcendental equation is obtained in which the phenomenological parameter ξ used in the Yang expression of the anchor energy appears. The dependencies of the critical field and the saturation field as a function of the parameter A that characterizes the liquid crystal anchor energy on the cell walls is also obtained. It is important to note that when the A parameter increases, the critical field also increases and reaches an almost constant value. Meanwhile, the saturation field value rapidly increases with the increasing of the parameter A, which was to be expected because the saturation can not be reached for a rigid anchoring. The values of both critical and saturation fields depend on the ferronematic and the interaction energy W of the liquid crystal molecules with the ferromagnetic particles surface.

Another study was dedicated to the ferrocholesteric-ferronematic transition in the magnetic field concluding that the ferronematic - ferrocholesteric transition and ferrocolesteric - ferronematic transition fields are different. The formulas are reduced to those obtained for the nematic - cholesteric, cholesteric - nematic transitions when the volumetric fraction of the ferromagnetic particles in the mixture is null.

It also treats the behaviour of a homeotropic alignment of ferrocholesteric on cell walls in the magnetic and laser fields. The magnetic field is perpendicular to the cell walls, the laser beam propagates parallel to the magnetic field and the direction of the electric field is parallel to the walls of the sample. In the case that $\chi_a>0$ and $\varepsilon_a>0$ the magnetic field tends to maintain the homeotropic alignment and the laser field to make the transition to the TIC (invariant translational configuration) configuration. For a magnetic field larger than the ferrocholesteric- ferronematic transition, an ellipsoidal plot is obtained in the coordinate of r (confinement ratio) and I (laser beam intensity) resulting in the homeotropic ferronematic to ferrocholesteric transition can occur at laser intensities150 - 200 W / cm². In the case of $\chi_a<0$ and $\varepsilon_a>0$, both the magnetic field and the laser contribute to the disturbance of homeotropic relief, these values being dependent on the r - the confinement ratio.

Chapter 4 presents the dynamic behaviour of nematic and ferronematic liquid crystals in magnetic fields. Dynamic behaviour occurs when a magnetic field is suddenly applied to the system, or if, after applying a magnetic field whose value is greater than the value of the critical Freedericksz transition field, it is abruptly cancelled. Thus, the relaxation times for switching on or switching off the field can be calculated, This parameter is quite valuable for electro-optic or magneto-optic devices as they count the time needed by a molecule to reach its final position under the field action. The boundary conditions applied in this chapter, allowed me to solve the Euler-Lagrange equations for a maximum deviation of the director's below 55-60 degrees. The results obtained for the used ferronematic mixtures revealed the correctness of the Burylov-Raikher theory regarding the interaction of the liquid crystal and the ferromagnetic particles. The study of the dynamic behaviour of liquid crystals in magnetic fields allowed the development of some methods to determine the elastic constants, as well as of their rotational viscosity coefficient. This was done by the calculation of measuring relaxation times when applying and canceling a magnetic field.

A study of the influence of single wall nanotubes that are dispersed in liquid crystals subjected to either magnetic or electric fields on the dynamic behaviour of the liquid crystal was also conducted. Experimental set-up was designed for each case and the relaxation times were calculated for different nanotubes concentrations. The data were analysed and a theoretical model similar to the one proposed by Burylov and Raikher was developed. The experimental results were compared to the theoretical ones, finding a good agreement between them. Thus, we noticed that when applying an external field, the carbon nanotubes that are initially aligned parallel to the liquid crystal molecules reorient themselves more slowly than the liquid crystal molecules due to their larger size and mass. As consequence, the mixture's relaxation time when the field is switched on is higher than those of the pure liquid crystal. An reverse effect is obtained when the field is off. Then the nanotubes are getting to the planar position faster than LC molecules due to gravity force and the relaxation time decreases. The theory of this dynamic behaviour is presented, a theory that is validated by the experimental data obtained both in the electric field and in the magnetic field.

Chapter 5 is dedicated to the nonlinear behaviour of liquid crystals when interacting with laser radiation. First, I must notice that this effect appears as a result of molecular order in nematics and of their ability to change their orientation under the action of external fields (electric, magnetic or laser). Since they are not strongly connected to each other, they can be aligned by the field and change the refractive index of extraordinary ray. More specifically, the refractive index of the liquid crystal is dependent on the intensity of the laser radiation used. Considering that the intensity of the laser beam has a Gaussian distribution in space, after passing it through the liquid crystal, the wave front changes from plane into a concave shape, which makes the phenomenon of self-diffraction possible. Since the refractive index depends on the orientation of the liquid crystal molecule relative to the direction of the laser beam, it is necessary to make possible the deviation of the nematic director by the electric field of the laser radiation. The first case from which I started this study was when the planar oriented liquid crystal cell is inclined towards the laser beam direction so that the beam's electric field intensity vector makes an angle different from zero with the liquid crystal molecules. Another situation is when a magnetic field, higher than the Freedericksz, is applied to a liquid crystal. Thus, inside the cell, the director orientation continuously changes in a direction perpendicular to the cell walls. In this situation, it is no longer necessary for the liquid crystal cell to be tilted and the laser beam may fall perpendicularly to the nematic director. The same considerations can be made with the application of an electric field. In this case, I used an electric field to change the molecular orientation to vary the angle between the molecular director and the electric component of the applied laser beam. In this case we could control the nonlinear effect by the applied field as long as the field was high enough to get over the backflow effect. An interesting situation was when hybrid cells are used. A hybrid cell has a planar alignment on one side and a homeotropic one on the other side. In this case the angle made by the nematic director with the electric field intensity of the applied laser beam has a continuous variation between the cell walls and the nonlinear effects appear more clearly.

Chapter 6 contains the directions of scientific and didactic development, and the summaries of my most relevant papers. I intend to continue the research on nematic mixtures with single or multi walled carbon nanotubes as well as with other carbon based nanoparticles (graphenes or fullerenes). The studies will be concentrated not only on their influence on the Freedericksz transitions and dynamic behaviour but I will also study their electric properties such as dielectric constants, conductivity, resistance or capacity. Since nanoparticles are more and more used in various fields from medicine to electronic devices I will take the advantage of the liquid crystal to organize these particles through the interaction forces and study other nanoparticles such as quantum dots or ferroelectric particles.