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The complex, 3D modeling and experimental investigation of the acousto-optical interaction

PhD thesis booklet

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Preliminaries

The acousto-optical interaction has been known for almost a century; its applications have become fundamental in the last fifty years. The acousto-optical devices are frequently used, indispensable elements of high technology and modern science, as they have extraordinary features. Yet, even today, the interaction itself – with widespread applications and scientific importance – does not have a precise numerical description. Though the investigation of the AO interaction is the subject of several scientific papers and books, the results being the most comparable to the measurements are given by the method of the coupled wave equations, which is essentially a 1D model assuming a single, perfectly plane optical wave and acoustical wave. In reality neither the optical, nor the acoustical wave is completely plane, therefore the numerous scientific analyses do not and cannot provide the precise description of the interaction.

Research goals

According to our experiences, working with AO devices often raises important questions which can be answered only by a precise simulation. Furthermore, we deem that the AO devices could be optimized further, for that again a computer model would be crucial to calculate the diffraction efficiency for a given AO transducer and cell configuration.

In my PhD research, I had the goal to create as accurate AO model as possible.

My PhD work is about the detailed theoretical and experimental examination of the AO interaction. I created a complex numerical method with which the AO interaction can be calculated accurately, relatively rapidly and quite generally. The results of the calculation are verified by theoretical expectations and by different experimental methods.
Hopefully the model will contribute notably to further improvements of the AO devices.

New scientific results

I created and algorithmically tested a numerical method which calculates the optical wave propagation based on the Maxwell equations for the description of the AO interaction. The significant advantage of the method is the highly accurate, rapid and general calculation, which is unique in the literature. The generality means that the anisotropy of the crystal may be arbitrary (uniaxial, biaxial or isotropic, and the crystal axis may have arbitrary direction), the incident beam may have an arbitrary general distribution (e.g. Gaussian), the beam is monochromatic (or at least it has finite wavelengths), the optical entrance and exit planes are parallel, and the inhomogeneity is small, but the diffraction efficiency has no upper limit, it can be even saturated. The model assumes furthermore that reflecting beams do not occur and the periodical boundary condition may be applied orthogonally to the calculation direction. The assumptions are very well fulfilled in the AO interactions, therefore they do not limit the mentioned advantages.

Corresponding papers: [1, 2, 3]
The method summarized in Thesis 1 is improved further for the very important case where the medium of the interaction is optically active. Thus the numerical method can calculate accurately, rapidly and quite generally the AO interaction. The improvement is relevant not only because the combined discussion of the optical activity and the AO interaction is practically missing in the literature, but also because the activity significantly influences the diffracted intensity and in the majority of the AO devices the medium is optically active.

Corresponding paper: [3]

I created and algorithmically tested a numerical method which calculates the light refraction; the calculation is based on the Maxwell equations for the case where the optical entrance and exit planes are parallel. The advantage of the method is again the highly accurate, rapid and quite general calculation which is unique in the literature. The generality condition is the same as in Theses 1 and 2. The method is improved further for the case where parallel and homogeneous thin layers are placed on the entrance and exit planes.

By the help of the numerical method I presented an experimental method for the measurement of the optical activity. Using a He-Ne laser (633 nm), I published the measured value of the optical rotatory power and its variance for TeO₂, and demonstrated that the method can characterize the inhomogeneity. Both experimentally and by the simulation, I demonstrated that in case of parallel plated TeO₂ crystal (which is optically active and anisotropic) the intensity of the transmitted light beam fluctuates as a function of the angle of incidence.

Corresponding paper: [4]
I created and algorithmically tested a numerical method which calculates the homogeneous and anisotropic acoustical wave propagation in the non-collinear AO cell with high accuracy. The method calculating the acoustical propagation was combined with the optical models summarized in Theses 1 to 3, and thus the complex simulation of the AO interaction was created. The complex AO model describes the non-collinear AO devices very generally and, again, with high accuracy: both the optical and acoustical wave propagations are simulated by the calculation of the corresponding vectorial wave equations in 3D. The presented method is unique in the literature. The correctness of the complex model is verified experimentally.

Corresponding paper: [5]
Reference


