<u>Stimulated and Holographic Scattering.</u> OSE6330

Fall 2015. Instructor: Boris Y. Zeldovich

Day & Time and Place: <u>Mondays, Wednesdays, 10:30 to 11:45 AM</u> <u>Room A-214 CREOL</u>

> The difference between Holography and Nonlinear Optics,
> if exists at all, is quantitative only,
> with Holography being characterized by slower build-up time.
> Nicolaas Bloembergen.

The Course “Stimulated and Holographic Scattering” is devoted to the study of those processes in Nonlinear Optics, which are characterized by propagation of light in the media with the size considerably larger than the wavelength. One of the fundamental advantages of such processes is the possibility of highly efficient beam transformations at the values of Poynting vector well below the threshold of optical damage of the medium. These transformations require coherent addition of the waves scattered by different parts of the medium. In many important cases such coherence is achieved via scattering by volume gratings satisfying Bragg condition.

Stimulated Scattering of light beams possesses remarkable property of being produced by self-organized dynamic gratings that automatically satisfy Bragg condition for the scattering from the “pump wave” into the “signal wave”. Such self-organization allows for the transformation of laser light with poor angular and/or temporal characteristics into high-quality beams. That includes (but is not limited to) the processes of Optical Phase Conjugation. Recording of these gratings proceeds often in a manner identical to that in Volume Holography. On the other hand, Volume Bragg Gratings (VBGs) are now playing important role in laser technology. All that makes natural the study of the processes of both Stimulated Scattering and scattering by VBGs in one course.

The course covers the following subjects.

<u>1. Maxwell equations in a general inhomogeneous medium and ways to solve them.</u>

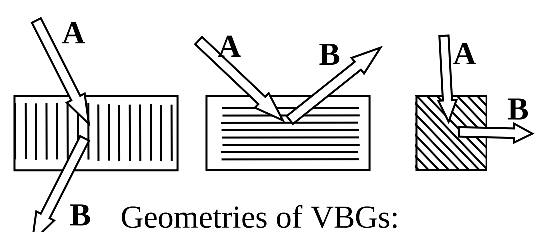
1.1. Separate roles of propagation speed (refractive index) and impedance. Chiral (Savchenko-Zeldovich) form of Maxwell equations.

1.2. Elementary solutions for homogeneous case as the basis for the system of first-order Slow Varying Envelope Approximation (SVEA) partial differential equations.

1.3. Non-diffracting approximation (Takagi equations, a.k.a. geometric optics approx.). Parabolic approx. for diffractional spread.

<u>2. Scattering of waves by VBGs.</u>

2.1. Kinematic approximation, i.e. low diffraction efficiency case. Polarizational properties of coupling. Notion of hologram strength. Detailed derivation of Bragg mismatch as a function of spectral and angular detuning and other factors. Spectral and angular selectivity in kinematic approximation. VBGs with transmission, reflection and corner (D. Psaltis) geometries. Information capacity of Volume Holographic Storage devices.



Geometries of VBGs:
Transmission, Reflective, Corner.

2.2. High efficiency VBGs. Boundary problems specific for transmission, reflective and corner VBGs. Bi-directional propagation as described by mono-directional computations: matrix methods, advantages and drawbacks. Constant-amplitude gratings and analytic theory of VBGs (H. Kogelnik); spectral and angular selectivity; various criteria: HWHIM, FWe^{-2}IM, etc. Computational convergence and numerical methods for reflective VBGs.

2.3. Walk-off effects as coordinate-space manifestations of spatial and spectral selectivity: Takagi equations and properties of their solutions.

2.4. ASADOG: Angular Selective Achromatic Diffraction Optical Grating device.

2.5. Apodizaton and adiabatic VBGs: Fourier properties for kinematic amplitudes and modal approach for high efficiency. Bargain between hologram strength and apodizaton quality.

2.6. Anisotropic gratings in anisotropic materials. Cholesteric Liquid Crystals.

3. Stimulated Raman Scattering (SRS)

3.1. Classical modulation picture. Importance of phase shift of the grating.

3.2. Steady-state gain g[1/meter]=G[meter/Watt]·S[Watt/meter^2] and linewidth Γ[1/sec, HWHM]; experimental data for G and Γ for various media and wavelengths.

3.3. Build-up process: theory and experiment.

3.4. Saturation of wave intensities in steady-state and in pulse-compression regime.

3.5. Anti-Stokes waves and Four-Wave Mixing (FWM).

4. Einstein-Hellwarth relationship between spontaneous and stimulated scattering.

5. Stimulated Brillouin Scattering (SBS).

5.1. Linearized hydrodynamics with electro-striction as the source of hypersound excitation. Dependence of G and Γ on the wavelength.

5.2. SBS in transient and in saturation regimes.

5.3. SBS of speckle-beams; SBS of focused beams; Optical Phase Conjugation.

5.4. Specific features of SBS in fibers.

6. Stimulated Rayleigh-Wing Scattering (SRWS), Kerr nonlinearity and self-focusing.

6.1 Orientation of molecules with anisotropic polarizability as one of mechanisms of Optical Kerr Effect and of SRWS. Polarizational and frequency properties.

6.2. Theorem about modulational instability of plane wave (Bespalov-Talanov).

6.3. Self-focusing in 1- and 2-transverse-dimensional problems. Estimates vs. exact inequalities. Spatial and temporal solitons in 1-tr.-D and in temporal domain.

6.4. Z-Scan (Hagan, Van Stryland, Sheik-Bahae): measuring n_2 and nonlinear absorption.

7. Thermal effects

7.1. Thermal self-focusing and defocusing: radically different form the cases with local nonlinearity. Propagation of light in long Gradient Index (GRIN) lenses.

7.2. Stimulated Thermal Scattering (STS).

8. Orientational nonlinearity of Liquid Crystals (LC).

8.1. Basics of dynamics and equilibrium of Nematic (NLC), Cholesteric (CLC) and Smectic (SLC) Liquid Crystals.

8.2. Bargain between the size of perturbation in LC, nonlinearity strength and response time.

8.3. Giant Orientational Nonlinearity and thin phase screen approximation. Ring pattern of external self-focusing. FWM process.

8.4. GRating Orientational Nonlinearity (GRON), Cross-Phase Modulation (CPM) and Orientational Stimulated Scattering (OSS).

8.5. Beam clean-up via OSS.

9. Processes in Photo-Refractive Crystals (PRC).

9.1. Donor- and acceptor-type dopants in wide-zone dielectric crystals.

9.2. Diffusion of charges, photovoltaic and photogalvanic effects.

9.2. Charge redistribution under inhomogeneous illumination: phase-shifted and un-shifted gratings of charge.

9.3. Pockels (linear electro-optic) effect and gratings of "tensorial refractive index".

9.4. Photo-voltaic Electro-Motive Force (PEMF) as a tool for sensitive heterodyne detection of speckle-fields (Stepanov). Non-Destructive Testing of mechanical parts with PEMF detection (Pepper, Klein).

9.5. Stimulated Diffusion Scattering. Self-bending of speckle-beams. Novelty filters (Feinberg, Anderson)

9.6. Mutual Phase Conjugation (PC), tail-biting schemes of PC, J. Feinberg's "cat conjugator".

9.7. Photorefractive solitons (Segev et al.).

9.8. Remarkable conservation laws for the FWM with complex coupling constants.

10. Similarities of time- and space-domain propagation, diffraction and dispersion.

11. Comparison of nonlinear processes in Optics and in lump-element circuit theory.

If time allows:

3.6. Saturation of molecular transition, mode-locking of Stokes and Anti-Stokes frequency comb, generation of sub-femtosecond pulses (Harris-Sokolov).

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Textbooks, primary:

R. W. Boyd. Nonlinear Optics, Academic Press, San Diego, 2002.

B. Ya. Zeldovich et al,. Principles of Phase Conjugation, Springer Verlag, Heidelberg, 1985.

Extra textbooks materials:

B. Ya. Zeldovich et al, Speckle-Wave Interactions in Application to Nonlinear Optics and Holography, CRC Press, Boca Raton, 1995.

Y. R. Shen, The Principles of Nonlinear Optics, Wiley, Paperback, 2002.

B. Ya. Zeldovich et al, The Orientational Optical Nonlinearity of Liquid Crystals, MCLC Journal's Special Issue, vol. 136, 1986, 139 pages, , Gordon and Breach, NY.

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