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14. ABSTRACT

We carried out detailed studies of Fabry-Perot resonances (transmission band edge resonances) in periodic layered structures involving birefringent layers. We have shown that the presence of birefringent layers with misaligned in-plane anisotropy can dramatically enhance the performance of the photonic-crystal resonator. It allows us to reduce its size by an order of magnitude without compromising on its performance. The key characteristic of the enhanced slow-wave resonator is that the Bloch dispersion relation of the periodic structure displays a degenerate photonic band edge. Such a situation can be realized in specially arranged stacks of misaligned anisotropic layers. On the down side, the presence of birefringent layers results in the slow-wave resonance being coupled only with one elliptic polarization component of the incident wave, while the other polarization component is reflected back to space.

15. SUBJECT TERMS
Fabry-Perot resonances (transmission band edge resonances) in periodic layered structures involving birefringent layers, slow light in photonic crystals and other periodic structures is associated with stationary points of the photonic dispersion relation, where the group velocity of light vanishes.

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Abstract

During the reported period we have studied a number of important phenomena related to High-Q photonic cavities.

We carried out detailed studies of Fabry-Perot resonances (transmission band edge resonances) in periodic layered structures involving birefringent layers. We have shown that the presence of birefringent layers with misaligned in-plane anisotropy can dramatically enhance the performance of the photonic-crystal resonator. It allows us to reduce its size by an order of magnitude without compromising on its performance. The key characteristic of the enhanced slow-wave resonator is that the Bloch dispersion relation of the periodic structure displays a degenerate photonic band edge. Such a situation can be realized in specially arranged stacks of misaligned anisotropic layers. On the down side, the presence of birefringent layers results in the slow-wave resonance being coupled only with one elliptic polarization component of the incident wave, while the other polarization component is reflected back to space. We have also shown how a small modification of the periodic layered array can solve the above fundamental problem and provide a perfect impedance match regardless of the incident wave polarization, while preserving the giant slow-wave resonance characteristic of a degenerate photonic band edge. Both features are of critical importance for many practical applications, such as the enhancement of various light-matter interactions, light amplification and lasing, optical and microwave filters, antennas, etc.

We have investigated general properties of slow light in photonic crystals and other periodic structures is associated with stationary points of the photonic dispersion relation, where the group velocity of light vanishes. It is shown that in certain cases, the vanishing group velocity is accompanied by the so-called frozen mode regime, when the incident light can be completely converted into the slow mode with huge diverging amplitude. The frozen mode regime is a qualitatively new wave phenomenon – it does not reduce to any known electromagnetic resonance. Formally, the frozen mode regime is not a resonance, in a sense that it is not particularly sensitive to the size and shape of the photonic crystal. The frozen mode regime is more robust and powerful, compared to any known slow-wave resonance. It has much higher

tolerance to absorption and structural imperfections.

Another subject of studies was magnetic Faraday rotation is widely used in optics and microwaves (MW). In uniform magneto-optical materials, this effect is very weak. One way to enhance it is to incorporate the magnetic material into a high-Q optical resonator. One problem with magneto-optical resonators is that along with Faraday rotation, the absorption and linear birefringence can also increase dramatically, compromising the device performance. We addressed this problem in the cases of optical microcavities and slow wave resonators. We have shown that a slow wave resonator has a fundamental advantage when it comes to Faraday rotation enhancement in lossy magnetic materials

I. OBJECTIVES.

- Theoretical analysis of how the listed below factors effect the performance of the photonic-crystal cavity:
(i) different boundary conditions, (ii) nonlinearity and losses, (iii) defects and localized states.

- Studies of slow wave phenomena in bounded photonic crystals with dissipation and different spectral singularities

- Enhancement of Faraday effect in nano-photonic structures.

- Enhancement of light-matter interactions in nano-photonic structures at optical and THz frequencies.

- Magnetic Faraday rotation and gain in active media

- Consistent electromagnetic theory for elementary charges

- Mathematics of slow light

II. STATUS OF EFFORT

- We established the relation between the character of spectral singularities of a bounded periodic array and its resonance properties.

- We carried out detailed analytical studies of the scattering problem for electromagnetic wave incident on a semi-infinite and finite periodic stratified media. This includes both the cases of normal or oblique incidence.

- We put forward a theory of absorption suppression in periodic composite structures and successfully applied this concept to magnetic multilayers.

- We have refined our studies of the Faraday rotation in lossy dielectric materials in the frozen mode regime and its application to the light amplification and lasing.

- We demonstrated that the magnetic Faraday rotation can be enhanced by up to two orders of magnitude, while avoiding the problems with absorption and linear birefringence. We also demonstrated a huge potential of the frozen mode regime in light amplification and lasing

- We extended our studied of wave packet in nonlinear media to a model of elementary charge. We constructed wave-corpuscle mechanics for elementary charges.

- We constructed a consistent electromagnetic theory of elementary charges which, in particular resolved an old problem of infinite self-energy.

- We advanced further our electromagnetic theory of elementary charges and introduced elementary potentials and fields in place of the single 4-potential and the electromagnetic field.

III. ACCOMPLISHMENTS/NEW FINDINGS.

Our work with Dr. Vitebskiy.

We discovered of the effect of dramatic absorption suppression in properly designed composite materials. We also demonstrated how slow wave resonator can be used for enhancement of nonreciprocal light-matter interactions, such as Faraday rotation.

We discovered of the effect of dramatic absorption suppression in properly designed composite materials. We also demonstrated how slow wave resonator can be used for enhancement of nonreciprocal light-matter interactions, such as Faraday rotation.

Our work with Dr. Babine.

We completed the developed a new fundamental model for an elementary charge.

We advanced further the new fundamental model for an elementary charge which includes now the Hydrogen atom model with experimental precision.

We introduced a new fundamental model for an elementary charges with no self-interaction.

Aaron Welter completed his graduate studies on the mathematics of slow light and he got his first postdoc positions in LSU and MIT for the next 3 years. He has developed a constructive perturbation theory for non-self-adjoint matrices with degenerate eigenvalues and found explicit recursive formulas to calculate the perturbation expansions of the splitting eigenvalues and their eigenvectors, under a generic condition.

IV. FACULTY AND GRADUATE STUDENTS SUPPORTED:

Dr. A. Babine, Dr. I. Vitebskiy, A. Walters

V. PUBLICATIONS:

- A. Figotin and I. Vitebskiy. "Absorption suppression in photonic crystals". Phys. Rev. B77, 104421 (2008).

- A. Figotin, I. Vitebskiy, A. Lisyansky, et al. "Inverse Borrmann effect in photonic crystals", Physical Review B 80, 235106 (2009).

- A. Babin and A. Figotin "Wave-corpuscle mechanics for elementary charges", Journal of Statistical Physics, (2010), 138, 912-954.

- A. Babin and A. Figotin "Some Mathematical Problems in a Neoclassical Theory of Electric Charges", to appear in Discrete and Continuous Dynamical Systems, Vol. 27, Number 4, August 2010.

- A. Figotin, I. Vitebskiy "Slow Wave Phenomena in Photonic Crystals", Laser & Photonic Reviews, 1-13 (2011).

- A. Figotin, I. Vitebskiy "Magnetic Faraday rotation in lossy photonic structures", Waves in Random and Complex Media, Vol. 20, No. 2, May 2010, 298–318.

- A. Babin and A. Figotin "Electrodynamics of balanced charges", Found Phys (2011) 41: 242–260.

- A. Welters "On Explicit Recursive Formulas in the Spectral Perturbation Analysis of a Jordan Block", SIAM J. MATRIX ANAL. APPL, Vol. 32, No. 1, pp. 1–22.

- A. Welters "On the Mathematics of Slow Light, Dissertation, University of California at Irvine.

VI. CONFERENCES and INVITED TALKS:

- A. Figotin and I. Vitebskiy, Electromagnetics Workshop, Brooks Air Force Base, San Antonio, Slow Wave Phenomena in Photonic Crystals, January, 2008.

- A. Figotn and A. Babin, "Nonlinear Dynamics of a System of Particle-like Wavepackets", University "Sapienza", Rome, Italy, July 2008.

- A. Figotin and I. Vitebskiy, "Absorption suppression in magnetic composites." Workshop on metamaterials, University of North Carolina, Charlotte, May 2009.

- A. Figotin and I. Vitebskiy, "Slow Wave Resonance in Photonic Crystals." Workshop on metamaterials, University of North Carolina, Charlotte, May 2009.

- A. Figotin and I. Vitebskiy, "Magnetic photonic crystals: Spectral Asymmetry, Electromagnetic Unidirectionality, Frozen Mode Regime." Lockheed Martin, Palm Dale, CA, March, 2009.

- A. Figotin and I. Vitebskiy, "Slow Wave Resonance for Light Amplification and Lasing." AFOSR workshop, Dayton, OH, September 2009.

- A. Figotn and A. Babin, "Wave-corpuscle mechanics for elementary charges", Caltech, Pasadena, February, 2009.

- A. Figotn and A. Babin, "Wave-corpuscle mechanics for elementary charges", Banff International Research Station, Banff, Canada, April, 2009.

- A. Figotn and A. Babin, "Wave-corpuscle mechanics for elementary charges", Localized Excitations in Nonlinear Complex Systems, Seville, Spain, July 2009.

- A. Figotn and A. Babin, "Wave-corpuscle mechanics for elementary charges", University of Paris 13, Paris, France, July 2009.

- A. Welters, UCI Mathematical Physics Seminar, University of California, Irvine, CA, November 2009

- A. Welters, SCSU Mathematics Colloquium, St. Cloud State University, St. Cloud, MN, November 2009

- A. Babin, A. Figotin "Derivation of classical and quantum mechanical effects for charged particles from dynamics of PDE", ICMS, Edinburgh, September, 2010

- A. Figotn and A. Babin, "Some Mathematical Problems in a Neoclassical Theory of Electric Charges", Weizmann Institute, Rehovot, Israel, August, 2010.

- A. Figotn and A. Babin, "Some Mathematical Problems in a Neoclassical Theory of Electric Charges", Jerusalem University, Mathematical physics minisimposium, Jerusalem, August, 2010.

- A. Welters, "Perturbation Analysis of Slow Waves for Periodic Differential-Algebraic Equations of Definite Type", Mathematical Physics Seminar, Mathematics Department, UCI, Oct. 2010.

- A. Figotin and I. Vitebskiy, Electromagnetics Workshop, Brooks Air Force Base, San Antonio, Electrodynamics of Balanced Charges, January, 2010.

- A. Welters, Arizona School of Analysis with Applications, Short Talk Session 2-8, University of Arizona, Tucson, AZ, March 2010

- A. Welters, 2010 AMS/MAA Joint Mathematics Meetings, AMS Session on Matrices and Tensors, San Francisco, CA, January 2010

- A. Figotn and I. Vitebskiy, "Spectral singularities and frozen modes in 2D and 3D photonic structures", Electromagentics workshop, San Antonio, January 2011.

- A. Figotn and A. Babin, "Some Mathematical Problems in a Neoclassical Theory of Electric Charges", Conference on Waves and Operator Theory, Texas A&M, January, 2011.

- A. Figotn and A. Babin, "Electromagnetism as a Fundamental Theory", Workshop on Future Directions in Applied Mathematics, Raleigh, North Carolina, March 2011.

- A. Figotn and A. Babin, "Some Mathematical Problems in a Neoclassical Theory of Electric Charges", UNC Charlotte, March, 2011.

- A. Welters, "Perturbation Analysis of Slow Waves for Periodic Differential-Algebraic Equations of Definite Type", 2011 AMS/MAA Joint Mathematics Meetings, AMS Session on Ordinary Differential Equations, New Orleans, LA, January 2011

- A. Welters, "Perturbation Analysis of Slow Waves for Periodic Differential-Algebraic Equations of Definite Type", PDE Seminar, Mathematics Department, UCLA, Feb. 2011.

VII. INTERACTIONS/TRANSITIONS.

- The research group of Prof. J. Volakis from OSU.

- The group from Lockheed Martin led by Dr. C. Chase (Magnetic metamaterials).

- The group of Prof. Hui Cao at Yale University (Frozen mode regime at optical frequencies).

- The group of Prof. Miguel Levy at Michigan Technological University (Nonreciprocal optical waveguides).

- The group of Prof. Michael Fiddy, Optics Center, University of North Carolina at Charlotte.