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令和元年11月

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1. New Routes to Studying the Dressed Photon

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Abstract

First, this paper reviews the history of studies on the dressed photon (DP) by classifying them into older and modern times, between which there exists a great difference in the concepts, principles, and methods involved. Quantum field theories, developed more recently, have succeeded in solving three problems originating from the intrinsic features of the light–matter interactions occurring in nanometric spaces. First, a variety of applications of these theoretical studies, which have resulted in the development of generic technology, are introduced. Second, the present status of experimental studies is reviewed. Among them, the fabrication and operation of novel light emitting devices using crystalline silicon (Si) are demonstrated. In these devices, the DP enabled high-power light emission even though Si is an indirect-transition-type semiconductor. Furthermore, it is shown that these devices exhibit a unique feature, named photon breeding. Third, a future outlook of DP research is presented, where it is pointed out that novel theoretical studies are required in order to support the rapid progress made in recent experimental studies and to develop further novel application technologies. As a route to such novel theoretical studies, three steps are presented, and several results derived from these steps are reviewed. Furthermore, a theory of micro–macro duality in the quantum field is presented as a powerful tool that will enable future progress in theoretical studies. Finally, a variety of phenomena in nano-systems, macro-systems, inorganic materials, and organic materials, which have similar features to those of the DP, are introduced. By referring to this similarity, it is pointed out that studies on the DP are connected to a more generic and broader science that is expected to produce a novel generic science, named off-shell science, in the near future.

2. Spatial and Temporal Evolutions of Dressed Photon Energy Transfer

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Abstract

It has been shown that dressed photon (DP) energy transfer exhibits unique autonomous spatial evolution features, and novel functional devices have been demonstrated as a first example of the practical application of this transfer. Temporal evolution features originating from nutating DP energy transfer followed by radiative relaxation have also been demonstrated. A novel film for highly efficient optical energy conversion is presented as a second example of the application of these features. It is suggested that these spatial and temporal evolution features can be analyzed based on theoretical models based on a quantum walk and a random walk. This film was placed on a silicon solar battery to convert UV light energy to visible light energy, resulting in an increased electrical power generation efficiency of 20.2%.

3. Creation and Measurement of Dressed Photons: A Link to Novel Theories

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Abstract

In order to identify the requirements in theoretical studies for analyzing the physical properties of dressed photons, this paper adopts a fiber probe developed for creating and measuring dressed photons. The principles and practices of using such a fiber probe in illumination and collection modes are reviewed. It is pointed out that the fiber probe can be replaced by a nano-particle and that multiple nano-particles exhibit a specific phenomenon of dressed photons, namely, autonomous energy transfer. A phase diagram is presented in order to identify the requirements in a novel theory for finding the optimum conditions for measuring dressed photons. It is pointed out that this theory should be able to describe the autonomy above and also the hierarchy that exists in the measurement. To meet these requirements, promising novel theoretical approaches are reviewed. One is the Clebsch dual field theory. The use of the quadrality scheme based on the category theory and a novel measurement theory are also suggested as promising approaches for analyzing the detailed physical properties of dressed photons, and this will open up a new field of off-shell science.

4. Experimental estimation of the maximum size of a dressed photon

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Abstract

This article describes experimental estimation of the maximum size of a dressed photon (DP) by a photochemical vapor deposition method that has been used for forming a metallic zinc nanoparticle (Zn-NP) on a sapphire substrate. Because of the localized feature of the DP and of a unique non-resonant DP–molecule interaction, this method succeeded in excluding the contribution of the propagating light in the Zn-NP formation. The size of the deposited Zn-NP increased with increasing deposition time. Finally, the size saturated to a value that was independent of the radius of curvature of the fiber probe tip and the wavelength of the light used for irradiating the end of the fiber probe. From these results, it was concluded that the experimentally estimated maximum size was 50–70 nm.

5. High-Power Infrared Silicon Light-emitting Diodes Fabricated and Operated using Dressed Photons

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Abstract

Mesh-electrode type and flip-chip type silicon light-emitting diodes were fabricated by using dressed photons. Their emission spectral profiles showed several peaks originating from phonons in a dressed-photon–phonon, from which the existence of a photon breeding phenomenon was confirmed. The highest optical output power emitted from these devices was 2 W at a substrate temperature of 77 K. The highest optical power density from the flip-chip type was as high as eight-times that from the mesh-electrode type.

6. Photon localization revisited

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Abstract

In the light of Newton-Wigner-Wightman theorem of localizability question, we have proposed before a typical generation mechanism of effective mass for photons to be localized in the form of polaritons owing to photon-media interactions. In this paper, the general essence of this example model is extracted in such a form as Quantum Field Ontology associated with Eventualization Principle, which enables us to explain the mutual relations, back and forth, between quantum fields and various forms of particles in the localized form of the former.

7. Principles and Practices of Si Light Emitting Diodes using Dressed Photons*

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Abstract

This paper reviews basic research and technical developments on silicon (Si) light-emitting diodes (Si-LEDs) fabricated by using a novel dressed-photon–phonon (DPP) annealing method. These devices exhibit unique light emission spectral profiles in the wavelength range 900–2500 nm, including novel photon breeding features. The highest optical output power demonstrated was as high as 2.0 W. It is pointed out that boron (B) atoms, serving as p-type dopants, formed pairs whose length was three-times the lattice constant of the host Si crystal. These B atom pairs are the origin of the photon breeding. A phenomenological two-level two-state (TLTS) model is presented, revealing that the external electric and optical fields, applied during the DPP-assisted annealing, drastically decrease the height of the potential barrier between the two states. This decrease is the reason why the spatial distribution of B atoms is efficiently modified by the DPP-assisted annealing even at low temperature. The TLTS model and a stochastic model confirm that the optimum DPP-assisted annealing is realized by setting the ratio of the electron injection rate and the photon irradiation rate to 1:1. A phase diagram is presented as an aid for developing a novel theory for realizing more efficient and higher-power Si-LEDs.

(*)This paper has been published in *Advanced Materials Letters*, vol.12 No.10, 2019, pp.860-867.

8. Logical Fallacy of using the Electric Field in Non-resonant Near-field Optics

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Abstract

We find that the electric field is not a suitable physical quantity to describe the response of *a non-metallic material* in the study of *non-resonant* near-field optics. In practice, we show the spin-less one-electron two-level system responds differently to longitudinal and transverse electric fields under the non-resonant condition. This difference originates from *the non-relativistic nature* of the system, and should exist in actual many-electron systems. For this type of system, it is a logical fallacy to use the constitutive equation in terms of the total electric field and the associated permittivity. Recognizing this fallacy, both experimental and theoretical progress is needed in the field of non-resonant near-field optics of non-metallic materials.

This manuscript was also uploaded to http://arxiv.org/abs/1807.10991

9. Micro-Macro Duality for Inductions/Reductions

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Abstract

Paradoxical appearance of negative metrics in the processes of emergences will be analyzed from the viewpoint of Morse theory, induced representations and of imprimitivity systems.

10. Gigantic Ferromagnetic Magneto-Optical Effect in a SiC Light-emitting Diode Fabricated by Dressed-Photon–Phonon-Assisted Annealing

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Abstract

This paper investigates the gigantic magneto-optical effect in a SiC light-emitting diode fabricated by dressed-photon–phonon (DPP)-assisted annealing. Very large values of the Verdet constant and the Faraday rotation angle were obtained, namely, 660 deg/A and 2480 deg/cm, respectively, at a wavelength of 405 nm. The remanent magnetization was 0.36 mT. The magnetization curve, acquired at 27 °C, exhibited a clear hysteresis characteristic. This behavior of the SiC crystal, equivalent to that of a ferromagnet, was attributed to Al atom pairs autonomously formed as a result of the DPP-assisted annealing.

11. Theory of Single Susceptibility for Near-_eld Optics Equally Associated with Scalar and Vector Potentials

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(Dated: September 28, 2018)

Abstract

A nonlocal response theory was developed to describe a many-electron system within the neighborhood of a nanostructure radiating the longitudinal and transverse electric fields, which are fundamentally reduced to the scalar and vector potentials (SP and VP). The coexistence of the SP and VP incidences distinguishes such a near-field optical system from the ordinary optical system, in which only the VP (under the Coulomb gauge) incidence survives far from the light source. This fact is the motivation for equal treatment of the SP and VP as the cause of the response in the near-_eld optical system. In the semiclassical treatment, the linear and nonlinear single susceptibilities are derived in the form of Heisenberg operators by the functional derivatives of the action integral of the matter with respect to the SP and VP. These single susceptibilities relate the SP and VP (as the cause) to the induced charge and current densities (as the result), and guarantee charge conservation and gauge invariance; this theory is free from gauge-_xing. It is necessary to consider the quantum many-electron effect (exchange-correlation effect) to make the ground state bounded in the non-perturbed system. This is done by employing the fundamental idea of density functional theory, instead of the ordinary unequal treatment of the SP and VP, that is, remaking the SP into a Coulomb interaction between electron charges. Applying the present linear response theory to the non-metallic material in a limited near-_eld optical system reveals that the electric field with the associated permittivity is notsuitable quantity to describe the response, instead, the SP and VP with associate single susceptibility are essential.

12. Embarking on theoretical studies for off-shell science guided by dressed photons

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Abstract

By noting that the dressed photon (DP) is a quantum field whose energy–momentum relation deviates from the mass-shell, novel theoretical studies of so-called off-shell science have been launched. This article reviews recent progress in these studies. After reviewing the characteristics of the DP as an off-shell quantum field, theories having a physical basis are introduced. These theories are an electromagnetic response theory and a theory based on spatio-temporal vortex hydrodynamics. Next, theories having a mathematical basis are introduced, and these can serve as helpful tools for gaining a deep understanding of the concepts of the physics-based theories above. These theories are a quantum probability theory and a quantum walk model. As a further helpful tool, a quantum measurement theory is introduced. A theory based on micro–macro duality is demonstrated, which serves as the foundation to embark on a stuy of off-shell science. Correlations among the theories reviewed here are also shown.

13. Novel functions and prominent performance of nanometric optical devices made possible by dressed photons

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Abstract

This paper describes the operation of an optical buffer memory device in order to demonstrate a novel function made possible by dressed photons (DPs). It was shown that output signals repeatedly appeared with a period of 150 ps by applying a readout optical pulse to the device. Next, to demonstrate the prominent performance achievable by DP devices, single-photon operation with a probability as high as 99.3 % was confirmed. Finally, the magnitudes of the dissipated and consumed energies of the DP device were shown to be 10^4 times lower than those of a CMOS logic gate.

14. Indications from dressed photons to macroscopic systems based on hierarchy and autonomy

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Abstract

This article describes the size-dependent momentum resonance of the dressed photon (DP) energy transfer. The features of the hierarchy and autonomy in DP energy transfer are reviewed, together with a description of experiments carried out to confirm these features, using DP devices, nano-fabrication, and energy conversion. It is pointed out that a novel theoretical model is required to analyze these features and that the quantum-walk model is a promising theoretical tool for this analysis.

15. Infrared lasers using silicon crystals

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Abstract

This article reviews infrared Si lasers fabricated by using dressed photons and capable of CW operation at room temperature. First, the performance of a basic laser device with a ridge waveguide is reviewed. It shows a single longitudinal-mode oscillation at a wavelength of 1.271 μm, manifested by the phenomenon known as photon breeding. Second, by improving the waveguide structure, a threshold current density as low as 40 A/cm^2 is demonstrated. Third, to realize a high-power Si laser device, a Si crystal with a large cross section, and without a waveguide structure, is employed. By improving the structure of the heat sink, by coating end-facets of the cavity with high-reflection films, and by increasing the cavity length to 30 mm, an optical output power as high as 100 W is obtained under triangular-wave (1 Hz repetition frequency) current injection equivalent to injecting a constant current. The peak wavelength in the multi-mode lasing spectrum is 1.95 μm, which depends on the energies of nine phonons. It is expected that this wavelength can be tuned to 1.3 μm by controlling the wavelength dependence of the reflectivity of the high-reflection films coated on the end-facets. The last part of this article compares the operating principle and performance of the present Si-lasers with those of conventional

16. Note on the physical meaning of the cosmological term

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Abstract

At first glance, the issue of dressed photon in the field of nano-optics seems to have nothing to do with cosmology which deals with phenomena with the largest spatial scales in nature. However, recent preliminary analyses on the mathematical structure of Clebsch dual field introduced as a part of explaining the generating mechanism of dressed photon implies the possibility that the emergence of the cosmological constant λ as the coefficient of the cosmological term λg_{ab} may be explained by the dynamical process of simultaneous conformal symmetry breaking of electromagnetic and gravitational fields. In this short note, as a supplemental explanation of this conjecture, we give a new explanation of the physical meaning of the cosmological term λg_{ab} by proving the hitherto unnoticed identity (1) in section 1.

17. Dressed photon phenomena that demand off-shell scientific theories

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Abstract

This paper presents experimental results on dressed photon (DP) phenomena that demand the quantum field measurement theory and quantum walk theory. In relation to the quantum field measurement theory, it is shown that disturbance of the DP momentum was observed. It is also shown that the linear relation between the cause and effect of the DP energy measurement is lost. An electric-dipole forbidden transition becomes an allowed transition, and the energy disturbance is enhanced by decreasing the probe–specimen distance. In relation to the quantum walk theory, it is shown that energy transfer of the DP and the Brownian motion of nanometer-sized particles were autonomously controlled.