Research Article

Perspective on an Emerging Frontier of Nanoscience Opened up by Dressed Photon Studies

Hirofumi Sakuma[*][ID], Izumi Ojima, Motoichi Ohtsu[ID]

Research Origin for Dressed Photon (RODreP) Yokohama, Kanagawa 221-0022, Japan
E-mail: sakuma@rodrep.or.jp

Abstract: The core parts of developing dressed photon (DP) research that require advanced knowledge of highly mathematical quantum field theory and their potentially important impacts on the wide spectrum of long-term scientific activities in general, not necessarily restricted to those in the natural science sector, are succinctly explained in this article. Although a considerable number of remarkable technological achievements in the field of nanophotonics have been attained by utilizing DP phenomena, from the theoretical viewpoint, they remain enigmatic, as in the case of dark matter and energy in cosmology. Under such circumstances, an intriguing working hypothesis (WH) for DPs is proposed by the authors of this article through a combination of Ojima's micro-macro duality theory and the Greenberg-Robinson theorem, claiming that the space-like momentum contribution is an inevitable element for quantum field interactions to occur. Note that, as the Schrödinger's cat thought experiment clearly shows, the widespread common quantum mechanics knowledge is incapable of explaining how the invisible quantum world is connected to our familiar visible classical world. In the above-mentioned WH, the main reason why we cannot explain either DPs or dark entities in cosmology is shown to have roots in the fact that the prevailing theories have not revealed an important role of spacelike momentum in connecting the quantum and classical worlds. Our new WH further shows that the entire universe is connected by an instantaneous spacelike entropic spin network, as in the case of quantum spin entanglement explained in mainstream physics. Since such a network may have a close relation with the nonlocal consciousness field, which seems to be the final frontier of physics, our perspective on such a possibility is briefly given in the final section of this paper.

Keywords: dressed photon, silicon light-emitting devices, micro-macro duality, off-shell quantum field, dark energy, dark matter, twin universes

Nomenclature

AI	Artificial intelligence
B	Boron
CC	Cross-correlation coefficient
CCC	Conformal cyclic cosmology
CP	Clebsch parameterization

CW	Continuous wave
DHR	Doplicher-Haag-Roberts
DP	Dressed photon
EPR	Einstein-Podolsky-Rosen
FWHM	Full-width at half-maximum
GNS	Gel'fand-Naimark-Segal
GR	Greenberg-Robinson
KG	Klein-Gordon
LED	Light-emitting diode
LSZ	Lehmann-Symanzik-Zimmermann
MMD	Micro-macro duality
NDE	Near-death experience
NL	Nakanishi-Lautrup
nm	Nanometer
NPi	ith-nanoparticle when i is attached to NP
PB	Photon breeding
PCVD	Photochemical vapor deposition
PMMA	Polymethyl methacrylate
PP	Psi phenomenon
QED	Quantum electrodynamics
QFT	Quantum field theory
QM	Quantum mechanics
SCSB	Simultaneous conformal symmetry breaking

1. Introduction

The aim of this article is to disseminate an important implication of dressed photon (DP) research [1], initiated by an inspired vision of the third author (M. O.) around the beginning of the 1990s, in the context of the progress to be made in many fields of natural and social sciences. A DP is an experimentally identifiable subtle electromagnetic field manifesting in a spherical form whose diameter varies in the range of less than several tens of nanometers (nm). Without exception, a DP is generated around a point-like singularity, such as the tip of an optical fiber or an impurity atom embedded in a given uniform medium. Figure 1 shows typical situations in which DPs can be generated.
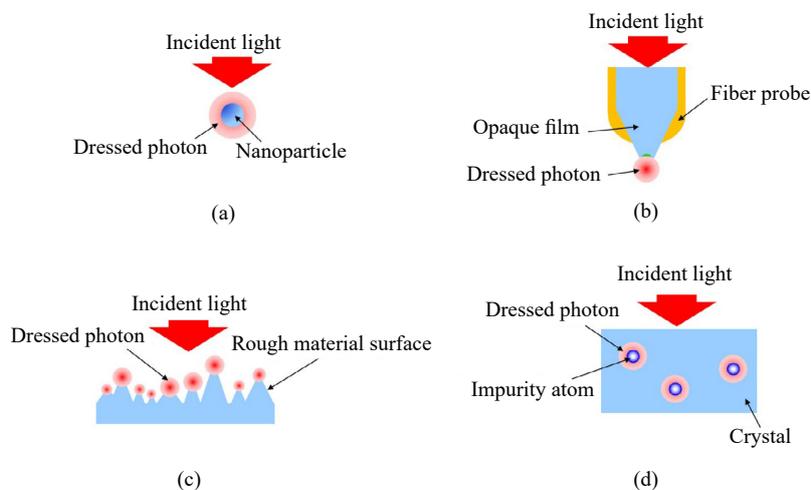
Figure 1. Experimental methods for generating DPs: (a) on a nanometer-sized particle; (b) on the tip of a fiber probe; (c) on bumps of a rough material surface; (d) on impurity atoms in a crystal

Responding to the demands of the times, during the first decade of this century, DP studies [2] created a new history in the field of optics. However, this rise of the DP research movement did not attract as much attention as one would think since DP phenomena are quite elusive in the sense that no existing theory can explain the generation mechanism. In some references, DP phenomena are described as well-known evanescent light fields, but we strongly support the view that these are quite different entities, namely, the former are generated by nonlinear light-matter field interactions, while the latter are boundary-trapped electromagnetic fields satisfying the linear Maxwell equation.

To understand why we cannot have a satisfactory theory of DP phenomena, first, we have to know the present status of quantum physics. Since many of the potential readers of this journal would not be experts in the field of advanced quantum field theory (QFT), giving the positioning of our targeted problem (the difficulty of formulating DP theory) in the Big Picture of QFT would be quite helpful. Actually, the difficulty arises from the disciplinary fragmentation existing between classical and quantum physics. The great and spectacular progress in quantum physics achieved in the 20th century made us regard classical physics as a somewhat obsolete discipline compared to quantum physics, which naturally led us to believe that the laws of quantum physics are the "genuine" physical laws, while those of classical physics are not exactly correct but approximate laws.

In fact, in standard physics textbooks, finding a simple explanatory phrase stating that electromagnetic waves are not longitudinal seems to be not rare, despite the fact that the existence of such longitudinal waves was reported, although not frequently, in eminent literature, for instance, Physical Review [3]. Recall that in "advanced" quantum electrodynamics (QED), through the process [4] of quantizing the electromagnetic field, the longitudinal mode is eliminated as an intangible and unobservable mode. We think that we often find the abovementioned phrase in physics textbooks because of a strong influence from the "advanced" QED without paying any attention to the "obsolete" classical physics. This being the case, borrowing a geological terminology, we can say that there exists a sharp made-up "theoretical fault" to be cleared at the dynamic boundary of the two realms of quantum and classical electromagnetism.

We believe that the ill effect of this "theoretical fault" is not restricted to electromagnetism but seems to widely penetrate into a considerable number of disciplines in physical sciences studying phenomena occurring at the boundary of the quantum and classical worlds. The widespread problem of the Schrödinger's cat thought experiment referred to in the abstract must be a well-known example. The endeavor to remove the "theoretical fault" is regarded as consistent integration of the quantum and classical worlds, and the micro-macro duality (MMD) [5, 6] theory to be explained here is a unique proposal aiming at such consistent integration of the quantum and classical worlds. The term consistent integration of different fields represents our central theme of the perspective we are going to explain in this article.

For those who do not have any prior knowledge of DPs, in section 2, we start our main discussion by briefly explaining DP phenomena and associated prominent technologies. To give a concise and lucid "bird's eye view"-type picture of the present status of QFT, namely, the aforementioned "Big Picture" of QFT, we will explain the essence of MMD theory in section 3, which plays a key role in our theoretical discussions. Then, in section 4, we will extend our discussion first to a spacelike Maxwell electromagnetic field and will discuss a novel heuristic model of DPs. In the final section 5, after briefly touching on a novel cosmology that is least expected from DP studies, an ambitious perspective on a possible connection between the "instantaneous" spacelike off-shell quantum field and yet-to-be-defined nonlocal consciousness field is tentatively given. Since consciousness is much more elusive than DPs and it has not gained "citizenship" in the world of physical sciences, our discussion on consciousness is not given from the viewpoint of pro and con arguments but from an advocate position.

2. A brief overview of DP phenomena and technologies

Numerous research papers and monographs describing the details of various DP experiments have been published thus far by the third author M. O. In this section, among others, we will give brief commentaries on ten highlighted phenomena that cannot be explained within the conventional framework of optics. The existence of these phenomena serves as an underlying motive of our novel research that we call "off-shell science", the present status of the theoretical construction of which is given in the subsequent sections 3 and 4, together with the reason why we call it "off-shell science", while the term "on-shell science" is reserved for the conventional framework. The list of ten phenomena is as follows:

1. The DP energy transfers back and forth between the two nanoparticles (NPs). (cf. Ch. 1 of [1] and [7])

2. The DP field is conspicuously disturbed and demolished by the insertion of NP_2 for detection. (cf. Ch. 1 of [7])
3. The efficiency of the DP energy transfer between the two NPs is the highest when the sizes of the NPs are equal. (cf. [8])
4. An electric-dipole-forbidden transition is allowed. (cf. Ch. 3 of [1])
5. The DP energy autonomously transfers among NPs. (cf. [9])
6. The irradiation photon energy $h\nu$ can be lower than the excitation energy of the electron E_{excite}. (cf. [10])
7. The maximum size $a_{(DP, Max)}$ of the DP is 40-70 nm. (cf. [11])
8. The spatial distribution of Boron (B) atoms varies and autonomously reaches a stationary state due to DP-assisted annealing, resulting in strong light emission from the Si crystal. (cf. Ch. 2 of [12])
9. The length and orientation of the B atom pair in the Si crystal are autonomously controlled by DP-assisted annealing. (cf. Ch. 3 of [12])
10. A light-emitting device fabricated by DP-assisted annealing exhibits photon breeding (PB) with respect to the photon energy, i.e., the emitted photon energy $h\nu_{em}$ is equal to the photon energy $h\nu_{anneal}$ used for the annealing. (cf. Ch. 1 and Ch. 3 of [12])

2.1 *Creation and detection of dressed photons*

A DP field is created in a complex system composed of photons and electrons (or excitons) in an NP (Figure 1(a)). This means that the photon "dresses" the exciton energy, and thus, this field was named a DP [13]. As an example of further dressing of the material energy, coupling between a DP and a phonon has been found.

To detect the DP that is created and localized on NP_1, the DP must be converted to propagating scattered light. This can be performed by inserting NP_2 into the DP field. Propagating scattered light is created by this insertion, and it reaches a photodetector in the far field, where it is detected. Although NP_1 and NP_2 may be considered a light source and a detector in this process, one should note the following two phenomena:

Phenomenon 1: The DP energy transfers back and forth between the two NPs.

Phenomenon 2: The DP field is conspicuously disturbed and demolished by the insertion of NP_2 for detection.

Furthermore, the following phenomenon was also found [8].

Phenomenon 3: The efficiency of the DP energy transfer between the two NPs is the highest when the sizes of the NPs are equal.

This phenomenon was named size-dependent resonance. Although the long-wavelength approximation has been popularly used in conventional optical scientific studies on light-matter interactions, it is invalid in the case of a DP because the spatial extent of a DP is much smaller than the wavelength of light. Due to this invalidity, the following phenomenon was found.

Phenomenon 4: An electric-dipole-forbidden transition is allowed.

The results of the above basic studies have ingeniously contributed to the realization of innovative generic technologies. For example, nanometer-sized optical functional devices were developed by using semiconductor NPs. They have enabled transmission and readout of optical signals via DP energy transfer and subsequent dissipation. Practical NOT logic gate and AND logic gate devices operated at room temperature have been fabricated by using InAs NPs [14]. The advantages include their superior performance levels and unique functionality, such as single-photon operation [15], extremely low energy consumption [16], and autonomous energy transfer [9]. These advantages originate from the unique operating principles of DP devices achieved by exploiting Phenomena 3 and 4. Furthermore, an inherent phenomenon was used for device operation.

Phenomenon 5: The DP energy autonomously transfers among NPs.

A non-von Neumann-type computing system has been proposed by using DP devices [17]. The ability to solve a decision-making problem [18] and an intractable computational problem [19] has been demonstrated.

The following two sections review two more examples of these technologies and present novel phenomena that originate from the intrinsic nature of DPs.

2.2 *Nanofabrication technology*

This part starts by reviewing an example of nanofabrication technology that uses a fiber probe (Figure 1(b)) or an

aperture for creating a DP. Next, a more practical technology is reviewed, in which neither a fiber probe nor an aperture is required.

2.2.1 *Technology using a fiber probe or an aperture*

This part reviews photochemical vapor deposition (PCVD) that involves molecular dissociation by a DP and subsequent deposition of the dissociated atoms on a substrate. $Zn(C_2H_5)_2$ was adopted as a specimen molecule. A DP was created on the tip of a fiber probe by irradiating the end of the fiber probe with light. Gaseous $Zn(C_2H_5)_2$ molecules, filled in a vacuum chamber, dissociated when these molecules moved into the DP field. The dissociated Zn atoms subsequently landed on a substrate and were adsorbed on the substrate. By repeating these processes, the number of adsorbed Zn atoms increased, resulting in the deposition of Zn atoms and the formation of a nanometer-sized metallic Zn-NP on the substrate.

For comparison, the wavelength in the case of dissociating $Zn(C_2H_5)_2$ molecules by using conventional propagating light had to be shorter than 270 nm (photon energy = 4.59 eV) to excite an electron in the $Zn(C_2H_5)_2$ molecule. By noting this requirement, the following ingenious contrivances (i) and (ii) were employed to confirm that the $Zn(C_2H_5)_2$ molecules were dissociated by the above DP.

(i) The wavelength of the propagating light for creating the DP was set longer than 270 nm. However, the $Zn(C_2H_5)_2$ molecules were expected to be dissociated by the DP on the tip due to the following phenomenon.

Phenomenon 6: The irradiation photon energy hv can be lower than the excitation energy of the electron E_{excite}.

That is, since the created DP is the quantum field accompanying the energies of the excitons (E_{excite}) and phonons (E_{phonon}) at the tip of the fiber probe, its energy is expressed as $hv_{DP} = hv + E_{excite} + E_{phonon}$. Thus, even though $hv < E_{excite}$, the DP energy hv_{DP} can be greater than E_{excite} [10].

(ii) The $Zn(C_2H_5)_2$ molecules were replaced by $Zn(acac)_2$ molecules [20]. $Zn(acac)_2$ is a well-known optically inactive molecule that has never been shown to be dissociated by propagating light. However, from **Phenomenon 4**, the possibility of it being dissociated by the DP was expected.

Figures 2(a) and 2(b) show images of Zn-NPs formed on sapphire substrates by dissociating $Zn(C_2H_5)_2$ molecules [10]. The wavelengths of the propagating light for creating the DP were as long as 684 nm and 488 nm. Figure 2(c) shows an image of a Zn-NP for which $Zn(acac)_2$ molecules were used [20]. The wavelength of the propagating light for creating the DP was 457 nm.
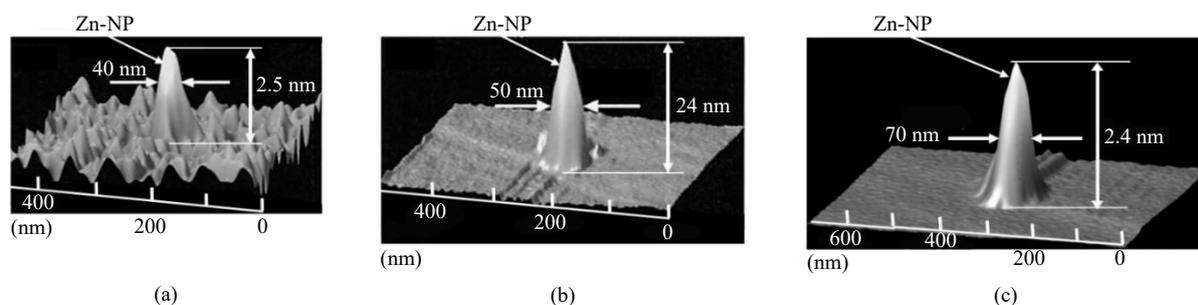
Figure 2. Shear-force microscopic images of Zn-NPs formed on sapphire substrates. The dissociated molecules are $Zn(C_2H_5)_2$ ((a) and (b)) and $Zn(acac)_2$ (c). The wavelengths of the propagating light for creating the DP are 684 nm (a), 488 nm (b), and 457 nm (c).

The maximum size $a_{(DP, Max)}$ of the DP was estimated from the above experimental results [11]. For this estimation, the increasing rate R of the full-width at half-maximum (FWHM) of the formed Zn-NP was measured [21].

The measured results showed that R was the maximum when the FWHM was equal to the tip diameter $2a_P$ of the fiber probe (a_P = 4.4 nm: tip radius). This was due to the size-dependent resonance of the DP energy transfer between the tip of the fiber probe and the formed Zn-NP (**Phenomenon 3**). Although a further increase in the deposition time increased the FWHM, R decreased to zero. Finally, the FWHM saturated. Figure 2 shows the profiles acquired after this saturation.

The FWHMs in Figure 2 were 40-70 nm. They were independent of the tip diameter, the wavelength and power of

the light used for irradiating the end of the fiber probe, and the species of molecules used. Since the spatial profile and size of the DP transferred from the tip of the fiber probe corresponded to those of the NP deposited on the substrate, the FWHMs in Figure 2 indicate the following phenomenon.

Phenomenon 7: The maximum size $a_{(DP, Max)}$ of the DP is 40-70 nm.

By using the above PCVD technology, a variety of two-dimensional patterns were formed by scanning a fiber probe [22]. To increase the working efficiency for pattern formation, a novel lithography technology was developed in which the fiber probe was replaced by a two-dimensional photomask [23]. A fully automatic practical photolithography machine was developed and used to form a diffraction grating pattern with a half pitch as narrow as 22 nm [24]. It also produced a two-dimensional array of the nanometer-sized optical devices reviewed in subsection 2.1 [25] and practical devices for soft X-rays (a Fresnel zone plate [26] and a diffraction grating [27]).

2.2.2 Technology that uses neither fiber nor aperture

This part reviews a technology for autonomous smoothing of a material surface that requires neither fiber probes nor apertures. The material to be smoothed is installed in a vacuum chamber, and the chamber is filled with gaseous molecules. By irradiating the material surface with light, DPs are created at the tips of the bumps on the rough material surface (Figure 1(c)). That is, the bumps play the role of fiber probes for creating DPs. If the molecules move into the DP field, they are dissociated. The chemically active atoms created as a result of this dissociation selectively etch the tips of the bumps away, while the flat part of the surface remains unchanged. The etching autonomously starts upon light irradiation, and the surface roughness gradually decreases as etching progresses. The etching autonomously stops when the bumps are annihilated and the DPs are no longer created.

The disc surface of a synthetic silica substrate (30 mm diameter) was etched by using gaseous Cl_2 molecules. Although light with a wavelength shorter than 400 nm was required for conventional photodissociation, the present method used visible light with a wavelength of 532 nm based on **Phenomenon 6**. Etching by active Cl atoms decreased the surface roughness to as low as 0.13 nm. A laser mirror was produced by coating a high-reflection film on the smoothed substrate surface. Its damage threshold for high-power ultraviolet laser light pulses was evaluated to be as high as twice that of the commercially available strongest mirror whose substrate surface was polished by a conventional chemical-mechanical polishing technology [28].

Gaseous O_2 molecules can also be used for autonomous etching because the O atoms created by dissociation are chemically active. The advantage is that etching can be carried out in atmospheric conditions by using O_2 molecules in air, and thus, a vacuum chamber is not required. Figure 3(a) shows the experimental results of etching a plastic polymethyl methacrylate (PMMA) surface [29]. Although ultraviolet light with a wavelength shorter than 242 nm was required for the conventional photodissociation of O_2 molecules, light with a longer wavelength λ_{DP} = 325 nm was used here due to **Phenomenon 6**. For comparison, Figure 3(b) shows the result of etching using conventional photodissociation, for which the wavelength $\lambda_{Conventional}$ of the light used was as short as 213 nm.
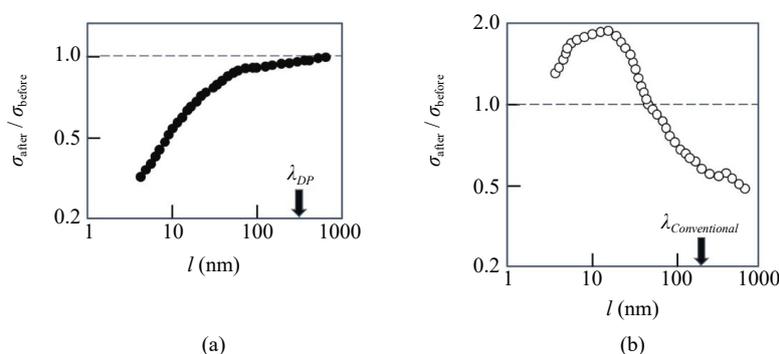
Figure 3. Ratio of the standard deviation of the roughness of the PMMA surface before and after etching. (a) and (b) are the results acquired by illuminating the surface with light with a wavelength of λ_{DP} = 325 nm and $\lambda_{Conventional}$ = 213 nm, respectively. The downward arrows represent the values of l that are equal to the above wavelengths.

In Figures 3(a) and 3(b), the surface roughness was evaluated from its standard deviation $\sigma(l)$. The horizontal axis l represents the period of the roughness of the surface. The vertical axis represents the ratio $\sigma_{after}/\sigma_{before}$ between the $\sigma(l)$ values before (σ_{before}) and after (σ_{after}) etching [29]. Figure 3(a) shows that $\sigma_{after}/\sigma_{before} < 1$ in the range $l < \lambda_{DP}$, through which the contribution of the subwavelength-sized DP is confirmed. A drastic decrease in $\sigma_{after}/\sigma_{before}$ can be observed in the range $l < 40\text{-}70$ nm, which again confirms **Phenomenon 7** regarding the maximum size of the DP. In contrast to Figure 3(a), Figure 3(b) shows that $\sigma_{after}/\sigma_{before} < 1$ in the range $l > \lambda_{Conventional}$. This means that the etching was effective only in the superwavelength range.

Since DPs are always created at the tips of the bump on the material surface under light irradiation, the present autonomous etching has been applied to smoothing of a variety of surfaces and materials: the side surface of a diffraction grating [30], the surface of a photomask used for conventional ultraviolet lithography [31], and the surfaces of GaN crystals [32], transparent ceramics [33], and diamonds [34].

2.3 Silicon light-emitting devices

Crystalline Si has long been a key material supporting the development of modern technology. However, because Si is an indirect-transition-type semiconductor, it has been considered to be unsuitable for light-emitting devices. The momentum conservation law requires an interaction between an electron-hole pair and phonons for radiative recombination. However, the probability of this interaction is very low. Nevertheless, Si has been the subject of extensive study for the fabrication of light-emitting devices [35, 36]. The above problems have been solved by using DPs because the phonons in a DP can provide momenta to the electron to satisfy the momentum conservation law [37, 12]. For device fabrication, DPs were created by irradiating a Si crystal with light. For device operation, DPs were created by electronic excitation.

For fabrication, an As atom- or Sb atom-doped n-type Si substrate was used. As the first step, the substrate surface was transformed to a p-type material by implanting B atoms, forming a p-n homojunction. Metallic films were coated on the substrate surface to serve as electrodes. As the next step, this substrate was processed by a fabrication method named DP-assisted annealing. Joule heat was generated by current injection, which caused the B atoms to diffuse. During this Joule annealing, the substrate surface was irradiated with light (wavelength $\lambda_{anneal} = 1.342$ μm). Because its photon energy $h\nu_{anneal}$ (= 0.925 eV) was sufficiently lower than the bandgap energy E_g (= 1.12 eV) of Si, the light could penetrate into the Si substrate without suffering absorption. Then, the light reached the p-n homojunction to create a DP on an impurity B atom (Figure 1(d)). The phonons in the created DP could provide momenta to a nearby electron to satisfy the momentum conservation law, resulting in stimulated emission of light. The emitted light propagated from the crystal to the outside, which indicated that part of the Joule energy used for diffusing B atoms was dissipated in the form of optical energy, resulting in local cooling that locally decreased the diffusion rate. As a result, through the balance between heating via the Joule energy and cooling via the stimulated emission, the spatial distribution of B atoms varied and autonomously reached a stationary state. This stationary state was expected to be the optimum for efficient creation of DPs and for efficient light emission because the probability of spontaneous emission was proportional to that of the stimulated emission described above. After DP-assisted annealing, the Huang-Rhys factor, a parameter representing the magnitude of the coupling between electron-hole pairs and phonons, was experimentally evaluated to be 4.08 [38]. This was 10^2-10^3 times higher than that before DP-assisted annealing.

The above fabricated device was operated as a light-emitting diode (LED) by simple current injection. By injecting a current of 3.0 A into the device with an areal size of 0.35 mm by 0.35 mm, a continuous wave (CW) output optical power as high as 2.0 W was obtained at a substrate temperature of 77 K. A power as high as 200 mW was obtained at room temperature (283 K) [39]. These results confirmed that the following phenomenon occurs.

Phenomenon 8: The spatial distribution of B atoms varies and autonomously reaches a stationary state due to DP-assisted annealing, resulting in strong light emission from the Si crystal.

Note that the photon energy emitted from conventional LEDs is governed by E_g. However, for the present Si-LED, the light emission spectra acquired at a temperature of 283 K and an injection current of 2.45 A [39] clearly showed a high spectral peak $h\nu_{em}$ at $E_g - 3E_{phonon}$, where E_{phonon} is the phonon energy. The origin of this spectral peak was attributed to the spatial distribution of B atoms that was autonomously controlled during DP-assisted annealing [40]. The measured three-dimensional spatial distribution of B atoms at the p-n homojunction indicated that the B atoms were apt to form pairs with a length $d = 3a$ (a is the lattice constant of the Si crystal (= 0.54 nm)) and that the formed pairs

were apt to orient along a plane parallel to the top surface of the Si crystal [41]. That is, the following phenomenon was found.

Phenomenon 9: The length and orientation of the B atom pair in the Si crystal are autonomously controlled by DP-assisted annealing.

Note that the required phonon momentum must be h/a for radiative recombination of the electron (at the bottom of the conduction band at the X-point in reciprocal space) and the positive hole (at the top of the valence band at the Γ-point) to occur. Since the phonon momentum is $h/3a$ when $d = 3a$, the DP created and localized at this B atom pair provides the momenta of three phonons to the electron. As a result, $h\nu_{em}$ is expressed as $E_g - 3E_{phonon}$, and its value is 0.93 eV (E_{phonon} = 65 meV), which is nearly equal to the photon energy $h\nu_{anneal}$ (= 0.95 eV) irradiated during DP-assisted annealing. This indicates that the irradiated light served as a breeder that created a photon with energy $h\nu_{em} = h\nu_{anneal}$ and manifested the following phenomenon.

Phenomenon 10: A light-emitting device fabricated by DP-assisted annealing exhibits photon breeding (PB) with respect to the photon energy; i.e., the emitted photon energy $h\nu_{em}$ is equal to the photon energy $h\nu_{anneal}$ used for the annealing.

PB was also observed with respect to the photon spin. That is, the polarization direction of the emitted light was identical to that of the light irradiated during DP-assisted annealing [41].

The fabricated Si-LED was demonstrated to work as a relaxation oscillator upon injection of a direct current, yielding an emission pulse train [42]. As an advanced version of this experiment, the 2nd-order cross-correlation coefficient (CC) was measured to evaluate the photon statistical features of the emission from small light spots on the device surface, which took the form of a pulse train (duration and repetition frequency of 50 ps and 1 GHz, respectively) [43]. Figure 4 shows the value of the CC evaluated by a Hanbury Brown-Twiss experimental setup [44]. It presents two features. One is that the CC is smaller than unity in the range of time difference of the measurements by two independent detectors $|\tau| < 20$ ns. This indicates the photon antibunching phenomenon that is an inherent feature of a single photon. The other feature is that the CC takes a nonzero value at $\tau = 0$, although it is less than 1×10^{-2}. This small nonzero value is attributed to the photons generated from multiple light spots located in close proximity to each other on the Si-LED surface.
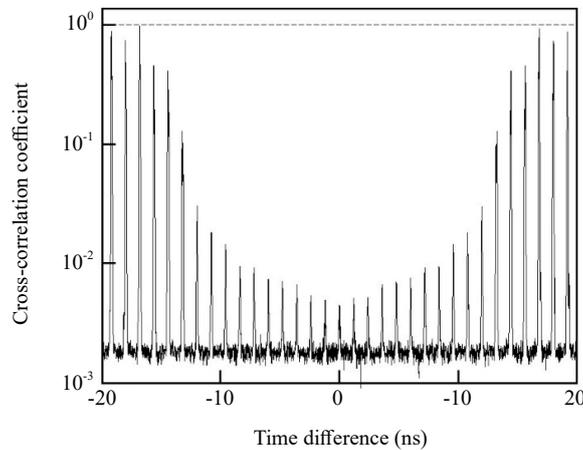
Figure 4. Second-order CC measured as a function of the time difference of the measurements by two independent detectors

These two features suggest the possibility that an emitted cluster of photons behaves as if it is a single photon. This possibility can be conjectured to be related to the localizable property of the spin-zero particle we noted [43] in relation to the Wightman theorem [45]. Namely, if the observable positions of given spin-zero quantum particles are sufficiently close, then the cluster of these particles would behave as if it is a single quantum particle with the accumulated amount of energy.

At the end of this section, the fact that Si lasers have also been fabricated by DP-assisted annealing should be briefly reviewed. One example is a CW single-mode laser with a ridge waveguide structure of 500 μm length operated

under room temperature (Figures 5(a) and 5(b)) [46]. Another example is a similarly operated quasi-CW multi-mode high-power laser (maximum output power = 100 W) with a long cavity (30 mm length) (Figure 5(c)) [7, 47]. PB was also observed for these devices.
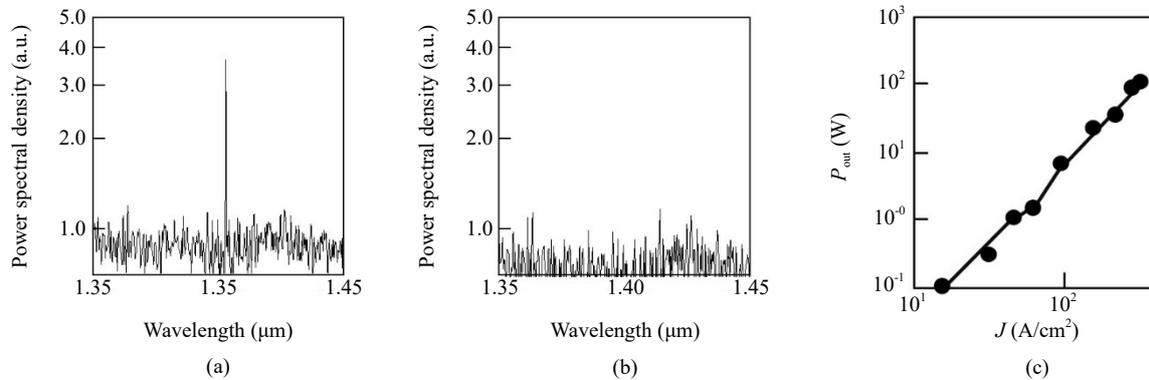
Figure 5. Light emission spectra and output optical power of Si lasers. (a) and (b) Single-mode laser: spectral profiles above (injected current density $J = 42$ A/cm^2) and below ($J = 38$ A/cm^2) the threshold, respectively. The threshold current density Jth is 40 A/cm^2. (c) High-power laser: Relation between J and the output optical power.

3. On the essence of micro-macro duality theory

3.1 *From macro to micro as an inductive approach*

We can safely say that for the majority of researchers in the fields of physics and engineering, except for experts in theoretical or mathematical physics, knowledge of QFT must be foreign to them, even though they are familiar with the standard framework of quantum mechanics (QM), where the state and associated physical quantities of a given quantum system are represented by a unit vector and self-adjoint operators defined on the Hilbert space $\mathfrak{H}$, respectively. The aim of this and the following subsections is therefore twofold: to clarify the important difference between QM and QFT and to plainly explain MMD theory, which adopts a methodology of algebraic formulation of the relativistic quantum field. Since these two subjects are highly mathematical in nature, we will explain the basic outline of their conceptual structures without touching on the sophisticated mathematics involved.

The fundamental framework of QFT consists of a couple of elemental concepts, namely, the quantum observable, which characterizes a given micro quantum system, and the quantum state, which determines the way in which the former manifests itself macroscopically. The aim of QFT as a physical theory is to explain how the structural interdependent relation changes in four-dimensional spacetime, which is called the dynamics of the system. In considering the characteristics of the quantum observable and quantum state, noting that these concepts are not directly recognizable concepts through visible phenomena in the macro classical world is particularly important. To appreciate their realistic meanings, we will inevitably employ analogies with classical physics (called the quantum-classical correspondence) together with the correct understanding of measurement processes.

The related important aspect of the quantum field is the fact that, unlike the classical field, not all of it is observable. In the algebraic QFT with which MMD theory is described, the quantum field is investigated through the associated noncommutative algebra $\mathfrak{F}$, and an observable is shown to be an element of a certain partial ring $\mathfrak{A}$ of $\mathfrak{F}$ ($\mathfrak{A} \in \mathfrak{F}$). A well-known example of an unobservable is a quantity that satisfies Fermi statistics. Although a "Fermi state" (a state in which fermionic fields exist) does not create any problems, we cannot directly observe such a quantity because it obeys the anticommutation relation that breaks the Einstein causality. Since electrons and protons are well-known and important fermions in particle physics, we see that the quantum field inevitably includes such an invisible field as to break the Einstein causality. We think that the outcome of the Bell's inequality test [48] for the Einstein-Podolsky-Rosen (EPR) dispute [49] seems to be consistent with this fact.

The starting point of MMD theory is the abstract sector theory of Doplicher-Haag-Roberts (DHR) [50-52], where sector means a collection of states for which the principle of superposition in quantum physics holds well. Recall that

in the classical special theory of relativity, the Poincaré group as the transformation group acting on the outer physical fields plays an important role in identifying the invariants of the fields. A similar situation holds for the inner quantum field $\mathfrak{F}$ and its transformation group G. In the case where $\mathfrak{F}$ possesses the internal symmetry associated with the action of G, the observable $\mathfrak{A}$, is usually given by the fixed partial ring of $\mathfrak{F}$ denoted by the symbol.

$$\mathfrak{A} = \mathfrak{F}^G, (\mathfrak{A} \in \mathfrak{F}, G = Gal(\mathfrak{F} / \mathfrak{A})) \tag{1}$$

where *Gal* denotes the Galois group fixing $\mathfrak{A}$ in $\mathfrak{F}$.

Since experimental validation is the most important element of physical theories, we can regard DHR's sector theory as an ambitious attempt to construct a quantum field theory based solely on the information on observable $\mathfrak{A}$. The key ingredient of their attempt is called the DHR selection criterion, which sorts the appropriate representations to be considered for satisfactory implementation of their scheme. The detailed explanation of it is beyond the scope of this article. The bottom line of DHR's sector theory is that by applying the selection criterion, based solely on the appropriate data on $\mathfrak{A}$, we can construct not only G but also $\mathfrak{F}$ to satisfy Equation (1).

3.2 *From micro to macro as a deductive approach*

In this subsection, we clarify the emergence process of the macro classical world; namely, we show, by improving the basic concept of sector in DHR's theory, how the macro classical world emerges from the micro quantum world. There are two important aspects of this emergence process. One is related to the degrees of freedom of the physical variables under consideration, and the other is directly tied to the specific problem of generalization of sector notion from the viewpoint of physics.

At the beginning of the previous subsection, we started our discussion by referring to the readers' unfamiliarity of QFT compared to QM. One of the decisive differences between QM and QFT comes from the difference in the degrees of freedom of the physical variables belonging to the dynamical system under consideration. If the number of degrees is finite, then the dynamics of a given system can be described by QM, whereas in the case of infinite degrees of freedom, QFT takes over. The Stone-von Neumann uniqueness theorem states that there exists only one sector for a QM system, which clearly shows that for a QM system, there is no room for the classical world to emerge since a sector is the states for which the principle of superposition in quantum physics holds well. In other words, a sector is defined as the irreducible representation of $\mathfrak{A}$. In what follows, we use the terms state and representation synonymously. In algebraic QFT, the state ω of $\mathfrak{A}$ is alternatively referred to as the Gel'fand-Naimark-Segal (GNS) representation $(\mathfrak{H}_\omega, \pi_\omega)$ where $\mathfrak{H}$ and π denote the Hilbert space and a linear operator on it, respectively.

DHR's sector theory constructed in the manner described above, however, suffers from serious flaws from the viewpoint of a physical theory. In theoretical physics, a seminal work of Nambu [53] on the notion of (spontaneous) symmetry breaking of physical fields made this idea of paramount importance since a considerable number of intriguing phenomena can be explained by such a process. Unfortunately, G in DHR's sector theory automatically has a unitary representation, and all the states reduce to the state with a G-invariant vacuum without symmetry breaking. In addition, from the definition of a sector as an irreducible representation of $\mathfrak{A}$ DHR's sector theory clearly cannot deal with thermodynamic states as mixed states.

Therefore, conceptual extension of the sector notion is definitely needed to overcome this difficulty. An effective remedy for this difficulty was proposed by Ojima [5]. Usually, by the equivalence of representations $\pi_1(A)$ and $\pi_2(A)$ of physical quantity A, we mean the unitary equivalence of $\pi_2(A) = U\pi_1(A)U^{-1}$, where U denotes a unitary operator. If we employ this, then π_1 and π_2 become nonequivalent even in the case that their difference is only multiplicity, for instance, of the form $\pi_1 = \pi$ and $\pi_2 = \pi \oplus \pi$. Ojima reached the solution that, as the classification of representations, if we employ the notion of quasi-equivalence $\pi_1 \approx \pi_2$ in which multiplicity is set aside, namely, unitary equivalence up to multiplicity, then the difficulty of DHR's sector theory can be overcome. The minimum unit of this new classification is called a generalized sector having factor representation with a trivial center.

We can show that for two arbitrary factor representations π_1 and π_2 if they are not quasi-equivalent, then they are disjoint. For the representation that is not a factor, there exist nontrivial centers as a commutative ring that enable break down of the representation uniquely into the form of the direct sum of disjoint factor representations through the process of simultaneous diagonalization. Thus, we see that these nontrivial centers play the role of the order parameters

describing the classical world, which is the emergence provcess of the macro classical world based on MMD theory.

3.3 On nonlinear field interactions

A typical example of the research on quantum field interactions is collision experiments in elementary particle physics. Theoretically speaking, the important elements in such experiments are as follows:

(1) the interacting nonlinear Heisenberg field φ, which must have a complicated spatiotemporal structure whose amplitude becomes predominant in the narrow spatiotemporal domain around the collision event, and

(2) the initial and final (noninteracting free) states of the field $\phi^{in/out}$ long before and after the collision event, which can be mathematically described as asymptotic fields $\phi^{as} \to \phi^{in/out}$ realized at $x^0 \to \mp\infty$, where x^0 denotes time in the spacetime Lorentzian coordinates $x = (x^0, x^1, x^2, x^3)$.

For simplicity, we assume that the field φ is a scalar field parameterized by a given mass m. The equations of motion for φ and ϕ^{as} become

$$(\Box + m^2)\varphi(x) = (\text{polynomial in } \varphi) := J_H \tag{2}$$

$$(\Box + m^2)\phi^{as}(x) = 0 \tag{3}$$

where the nonlinear term J_H is called the Heisenberg source current. Note that compared to the φ field, a nonlinear term is missing for the ϕ^{as} field. Without caring about the detailed explanation of mathematical expressions employed in the following system of equations (Equations (4) to (7)), if we formally write down φ, then we have

$$\varphi(x) \to \phi^{in/out}(x) \quad (\text{as } x^0 \to \mp\infty) \tag{4}$$

$$\varphi(x) = S^{-1}\{(\omega_0 \otimes id)(T[\varphi(x) \otimes 1]\exp(iJ_H \otimes \phi^{in}))\} \tag{5}$$

$$= \{(\omega_0 \otimes id)(T[\varphi(x) \otimes 1]\exp(iJ_H \otimes \phi^{out}))\}S^{-1} \tag{6}$$

The two symbols $\{S\}$ defined as

$$S = \{(\omega_0 \otimes id)(T\exp(iJ_H \otimes \phi^{in}))\} = \{(\omega_0 \otimes id)(T\exp(iJ_H \otimes \phi^{out}))\} \tag{7}$$

and $\{\exp(iJ_H \otimes \phi^{in/out})\}$ are the S(cattering)-matrix operator and an extended version of the Kac-Takesaki operator for an infinite dimensional system, and Equations (5) and (6) are called the Haag-GLZ expansion of φ.

Fortunately, there exists a helpful translation to decipher the above "hieroglyphic" description of quantum field interactions, which is called asymptotic completeness. It states that in the extremely long time limit of a scattering process controlled by the S matrix operator, the Heisenberg field φ generated from J_H can be transformed into asymptotic field(s) ϕ^{as} specified by Equation (3), and this field

(i) satisfies, with sufficient accuracy, the on-shell condition for the associated 4-momentum p^μ having the form $p^\nu p_\nu = m^2 \geq 0$, where the sign convention of the Lorentzian metric signature $(+ - - -)$ is employed and "shell" in the present context means the mass-shell parameterized by m, and

(ii) can also be described with the same accuracy by a pair of creation and annihilation operators.

The combined behaviors (i) and (ii) of the asymptotic field(s) ϕ^{as} are what Equations (5) and (6) mean, and the important relation between φ and ϕ^{as} is given by the Lehmann-Symanzik-Zimmermann (LSZ) formula [54].

Presumably, those familiar with optics would note why the key element S given in Equation (7) is called the scattering matrix. When a propagating electromagnetic field hits a small particle, it is reflected in a certain fashion depending on the given physical situation, which is called scattering of the electromagnetic wave. The quantum field interaction focusing on $\phi^{in/out}$ mentioned above resembles this scattering phenomenon in form, where $\phi^{in/out}$ correspond to the incident and reflected outgoing light fields far from the particle. The substantial difference is that the Heisenberg field φ arises from the nonlinear interactions of quantum fields, while the scattering process in optics can be described solely in terms of the linear Maxwell equation. In relation to this substantial difference, readers should pay attention

to Haag's no-go theorem [55] stating that there exist no unitary transformations connecting ϕ^{in} and ϕ^{out}. This no-go theorem clearly shows that the existing QFT cannot satisfactorily describe the nonlinear field interactions.

Nevertheless, we think that the impact of the LSZ formula on the particle physicist community is quite significant in the sense that it provides a quite useful formula for particle collision experiments by circumventing the awkward problem of nonlinearity. We further think that the advent of the LSZ formula would create the atmosphere in their community that the study of invisible off-shell quantum fields (fields free from the on-shell condition) directly related to nonlinear interactions is either an unattractive (in the sense that it is behind the scenes) or a too difficult theme such that many of them would not think much about it.

In introductory section 1, we referred to the "theoretical fault" existing between the quantum and classical worlds. The prevailing tendency of focusing mainly on the on-shell aspects of physical fields also seems to be related to the "theoretical fault" since nonlinear field interactions play essential roles in connecting the two worlds. To conclude this subsection and in preparation for developing our discussion further in the following subsection, here, we refer to the Greenberg-Robinson (GR) theorem [56, 57] claiming that the involvement of off-shell spacelike momentum field $p^v p_v = m^2 < 0$ (cf. $p^v p_v = m^2 \geq 0$ explained in item (i) of field(s) ϕ^{as}) is necessary for nonlinear quantum field interactions to occur.

4. Spacelike Maxwell's field and a novel DP model

The contents of electromagnetism in this section and of novel cosmology in the subsequent section are the epitome of our series of recent studies reported in several papers. The latest research outcomes in the respective fields were reported by Sakuma et al. [43, 58].

4.1 *Spacelike electromagnetic field*

In particle physics, a spacelike momentum field $p^v p_v = m^2 < 0$ is often considered the field of a tachyon (or tachyonic particle) moving with superluminal velocity. However, a wave packet moving with superluminal velocity is shown to be quite unstable [59], while a simple sinusoidal-type wave does not create any problems. Therefore, assuming that any spacelike momentum field p^μ does not give an expression of a particle but represents a nonlocal wavelike field is natural.

Having noted this important characteristic of spacelike fields, we now explain how the Maxwell equation can be extended into the spacelike momentum domain, which is required by the GR theorem for us to consider nonlinear quantum field interactions. Since the Coulomb mode relating to longitudinal waves missing in the conventional theory of QED must be the key element, we start by reinvestigating the dynamical process in which the longitudinal mode plays an important role in the Maxwell equation.

$$j^\mu = \partial_v F^{\mu v} = \partial_v (\partial^\mu A^v - \partial_v A^\mu) = [-\partial^v \partial_v A^\mu + \partial^\mu (\partial_v A^v)] \tag{8}$$

where j^μ and $F^{\mu v}$ denote an electric current and the electromagnetic field strength with vector potential A^μ. The mixed form of the energy-momentum tensor for Equation (8) is given by

$$T_\mu^v = -F_{\mu\sigma} F^{v\sigma} + \frac{1}{4} \eta_\mu^v F_{\sigma\tau} F^{\sigma\tau} \tag{9}$$

where η_μ^v denotes the Lorentzian metric tensor with signature $(+ - - -)$.

The quantization of the electromagnetic field cannot be done without using a gauge-fixing condition of some kind, which means that we have to specify $\partial_v A^v$ in a physically meaningful fashion. Here, we employ the Nakanishi-Lautrup (NL) B-field formalism [4] already referred to in section 1, which realizes manifestly covariant quantization. In the NL formalism, the Lorentz gauge condition $\partial_v A^v = 0$ can be generalized through the introduction of covariant linear gauges of the form.

$$\mathscr{L}_{\mathrm{B}} = B\partial_\nu A^\nu + \frac{\alpha}{2}B^2; \quad \partial_\nu A^\nu + \alpha\beta = 0, \partial^\nu\partial_\nu B = 0 \tag{10}$$

where $\mathscr{L}_{\mathrm{B}}$, B and α are a gauge-fixing Lagrangian density, the B-field and a real parameter, respectively. The second and third equations in Equation (10) give the gauge-fixing condition and the equation the B-field satisfies, respectively.

From the viewpoint of our present analysis focusing on the substantial (physical) property of nonvanishing longitudinal mode $\partial_\nu A^\nu$, the Feynman gauge corresponding to $\alpha = 1$ in Equation (10) is particularly important. The total Lagrangian density $\mathscr{L}_{\mathrm{total}}$ and its first variation with this gauge become

$$\mathscr{L}_{\mathrm{total}} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}(\partial_\nu A^\nu)^2, \rightarrow [-\partial_\nu F^{\mu\nu} + \partial^\mu(\partial_\nu A^\nu)]\delta A_\mu = 0. \tag{11}$$

By comparing the second equation in Equation (11) with Equation (8), we obtain

$$\partial^\nu\partial_\nu A^\mu = 0, \partial_\nu A^\nu = -B, \partial^\nu\partial_\nu B = 0. \tag{12}$$

In the conventional analysis of the energy-momentum conservation of Equation (9), we usually interpret $\partial^\nu T_\mu{}^\nu = F_{\mu\nu}j^\nu = 0$ as the consequence of $j^\nu = 0$, namely, no electric current exists. Note, however, that since Equation (8) reduces to $\{j^\mu = \partial_\nu F^{\mu\nu} = \partial^\mu(\partial_\nu A^\nu)\}$ by the first equation in Equation (12), this also holds well for the case in which we have $\partial^\nu T_\mu{}^\nu = F_{\mu\nu}\partial^\mu(\partial_\nu A^\nu) = 0$ under the condition that nonzero current $\partial^\mu(\partial_\nu A^\nu)$ (physically different from the electric current) is parallel to a Poynting vector field associated with $F_{\mu\nu}(F_{\mu\nu} \perp \partial^\mu(\partial_\nu A^\nu))$. Thus, we have shown that a longitudinal wave "current" having the form of

$$(j^\mu =)\partial_\nu F^{\mu\nu} = \partial^\mu(\partial_\nu A^\nu)) \tag{13}$$

is a physical current that satisfies the energy-momentum conservation, and we further see that for this particular choice of Feynman's gauge-fixing condition, the B-field equation $\partial^\nu\partial_\nu B = 0$ in Equation (12) formally corresponds to the gauge-invariant condition relating to conservation of "the current" $\{(j^\mu) = \partial^\mu(\partial_\nu A^\nu)\}$.

Next, we consider the extension of the Maxwell equation to the spacelike momentum domain $p^\nu p_\nu = m^2 < 0$. For the brevity of notation, in what follows, we redefine $\partial_\nu A^\nu$ as ϕ, namely,

$$\phi := \partial_\nu A^\nu, \quad \partial^\nu\partial_\nu\phi = 0 \tag{14}$$

The "gauge-invariant" orthogonality condition $F_{\mu\nu}(\partial^\nu\phi) = 0$ derived above is mathematically equivalent to a relativistic hydrodynamic equation of a barotropic (isentropic) fluid [58]. This observation suggests that we employ the method of the (two-parameter λ, ϕ) Clebsch parameterization (CP) to represent vector potential U^μ of spacelike electromagnetic field $S^{\mu\nu}$ since these two parameters play the role of canonically conjugate variables in the Hamiltonian dynamics of the barotropic fluid [60]. The detailed derivation of U^μ and $S^{\mu\nu}$ was already given in a few references [61-63], so here, we only show the main results, which can be classified into two, categories I and II. For the reason mentioned above, we call the spacelike electromagnetic field defined below the Clebsch dual (electromagnetic) field.

Category I

U^μ belonging to this category satisfies the lightlike condition of $(U^\nu)^*U_\nu = 0$, where $(\cdot)^*$ denotes the complex conjugate of $(\cdot)$. In this case, U_μ is defined in terms of two parameters λ and ϕ satisfying the following equations.

$$U_\mu = \lambda\partial_\mu\phi, \quad \partial^\nu\partial_\nu\lambda - (\kappa_0)^2\lambda = 0, \quad \partial^\nu\partial_\nu\phi = 0 \tag{15}$$

where κ_0 (or its inverse $l_{dp} := (\kappa_0)^{-1}$) denotes an important constant called the DP constant referred to in section 2. For concise representations of $S^{\mu\nu}$ and the associated energy-momentum tensor $\hat{T}_\mu{}^\nu$, we introduce two gradient vector fields that are perpendicular to each other:

$$L_\mu := \partial_\mu \lambda, \quad C_\mu := \partial_\mu \phi, \quad C^\nu L_\nu = 0. \tag{16}$$

With these new notations, the covariant representation of $S^{\mu\nu}$ is given by a simple bivector of the form

$$S_{\mu\nu} = L_\mu C_\nu - L_\nu C_\mu, \tag{17}$$

and we can show that U_μ is a tangential vector field along a null geodesic satisfying the wave equation on the right side:

$$U^\nu \partial_\nu U_\mu = -S_{\mu\nu} U^\nu = 0, \Longleftarrow\Longrightarrow \partial^\nu \partial_\nu U^\mu - (\kappa_0)^2 U^\mu = 0. \tag{18}$$

The energy-momentum tensor $\hat{T}_\mu{}^\nu$ corresponding to Equation (9) is defined as

$$\hat{T}_\mu{}^\nu = S_{\mu\sigma} S^{\nu\sigma} = \rho C_\mu C^\nu, \quad \rho := L^\nu L_\nu < 0, \tag{19}$$

$$\partial_\nu \hat{T}_\mu{}^\nu = S_{\mu\sigma} \partial_\nu S^{\nu\sigma} = S_{\mu\sigma} (\kappa_0)^2 U^\sigma = 0. \tag{20}$$

We see that $\hat{T}_\mu{}^\nu$ has dual representations of wave field $S_{\mu\sigma} S^{\nu\sigma}$ and particle field $\rho C_\mu C^\nu$, and the condition of negative density $\rho < 0$ corresponds to the removal of the particle mode in QED.

Category II

For spacelike U_μ that satisfies $(U^\nu)^* U_\nu < 0$ and is advected along a geodesic, it is redefined as

$$U_\mu := \frac{1}{2}(\lambda C_\mu - \phi L_\mu), \quad U^\nu \partial_\nu U_\mu = 0, \tag{21}$$

$$\partial^\nu \partial_\nu \lambda - (\kappa_0)^2 \lambda = 0, \quad \partial^\nu \partial_\nu \phi - (\kappa_0)^2 \phi = 0, \quad C^\nu L_\nu = 0. \tag{22}$$

The form of $S_{\mu\nu}$ remains the same as Equation (17), while $\hat{T}_\mu{}^\nu$ in this case assumes the form of

$$\hat{T}_\mu{}^\nu = \hat{S}_{\mu\sigma}{}^{\nu\sigma} - \frac{1}{2}\hat{S}_{\alpha\beta}{}^{\alpha\beta} \eta_\mu{}^\nu, \quad \hat{S}_{\alpha\beta\gamma\delta} := S_{\alpha\beta} S_{\gamma\delta}. \tag{23}$$

Since $\hat{S}_{\alpha\beta\gamma\delta}$ has the same antisymmetric properties as the Riemann tensor $R_{\alpha\beta\gamma\delta}$, including the first Bianchi identity $\hat{S}_{\alpha[\beta\gamma\delta]} = 0$, $\hat{T}_\mu{}^\nu$ becomes isomorphic to the Einstein tensor $G_\mu{}^\nu := R_\mu{}^\nu - Rg_\mu{}^\nu / 2$.

4.2 Novel heuristic model of a DP

In the preceding subsection, we have shown that the spacelike electromagnetic field $S_{\mu\nu}$ can be decomposed into a spacelike bivector of the form $\partial^\nu \partial_\nu \lambda - (\kappa_0)^2 \lambda = 0$. In our efforts to develop a heuristic model of a DP, we think that the analogy called the quantum-classical correspondence referred to in subsection 3.1 is quite helpful. As such a helpful analogy, we consider first the comparison between the above spacelike Klein-Gordon (KG) equation regarding λ and the Dirac equation

$$(i\gamma^\nu \partial_\nu + m)\Psi = 0, \tag{24}$$

which can be regarded as the "square root" of the timelike KG (type) equation: $(\partial^\nu \partial_\nu + m^2)\Psi = 0$. The Dirac equation for $(\partial^\nu \partial_\nu - (\kappa_0)^2)\Psi = 0$ therefore becomes

$$i(\gamma^\nu \partial_\nu + \kappa_0)\Psi = 0. \tag{25}$$

Additionally, for the Dirac equation (24), there exists an electrically neutral Majorana representation in which

all the values of the γ matrix become purely imaginary, so it reduces to $(\gamma^{\nu}{}_{(M)}\partial_{\nu}+m)\Psi=0$, which is isomorphic to Equation (25). Therefore, in our quantum-classical correspondence for this particular case, we can say that the Majorana field is the quantum counterpart of the classical solution of $\partial^{\nu}\partial_{\nu}\lambda-(\kappa_0)^2\lambda=0$.

Due to Pauli's exclusion principle, for the Majorana field as the fermionic field, the same state cannot be occupied by two fields. Therefore, the key question regarding the formulation of the (bosonic) Clebsch dual electromagnetic field is how the fermionic Majorana field fits into the former field. To answer this question, let us consider two different states of Majorana fields whose angular and linear momenta are given by $(M_{\mu\nu}, p^{\mu})$ and $(N_{\mu\nu}, q^{\mu})$, respectively. Note that two such fields can share the same Pauli-Lubanski vector W_{μ} describing the spin state of moving particles. Namely,

$$M_{\mu\nu}\,p^{\nu}=N_{\mu\nu}q^{\nu}=W_{\mu}, \tag{26}$$

where linear momenta p^{μ} and q^{ν} are orthogonal, i.e., $p^{\nu}q_{\nu}=0$. As we have shown in the preceding subsection, the spacelike electromagnetic field $S_{\mu\nu}$ is represented by a couple of simple bivector fields L_{μ} and C_{μ} that are perpendicular to each other (Equations (16) and (22)). Therefore, such a dynamic configuration in the classical Clebsch dual representation is consistent with the condition $p^{\nu}q_{\nu}=0$, and the bosonic property of spin 1 is realized by sharing the same W_{μ}, the sum total of which becomes 1.

To obtain a heuristic model of a DP, we utilize the theoretical analysis performed by Aharonov et al. [64], who studied the resulting behavior of the spacelike KG equation perturbed by a point source of the form $\delta(x^0)\delta(r)$, where r denotes the spatial coordinate(s). In our present analysis, we employ a spherical coordinate system in which r denotes the radial coordinate. Their analyses showed that the resulting time-dependent behavior of the solution is expressed as the superposition of a superluminal (spacelike) stable oscillatory mode and a timelike linearly unstable mode whose combined amplitude with a local peak initially tends to flatten with a speed slower than the light velocity. A timelike unstable solution arising from the perturbed spacelike KG equation has the form of $\hat{\lambda}(x^0,r)=\exp(\pm k_0x^0)R(r)$, where $R(r)$ satisfies

$$R''+\frac{2}{r}R'-(\hat{\kappa}_r)^2=0,\ \ (\hat{\kappa}_r)^2:=(k_0)^2-(\kappa_0)^2>0, \tag{27}$$

the solution of which is known as the Yukawa potential

$$R(r)=\exp(-\hat{\kappa}_r r)/r, \tag{28}$$

which rapidly falls off as r increases.

In the classical scenario, we can usually interpret a pair of these unstable solutions as follows. While $\hat{\lambda}_{(-)}:=\exp(-k_0x^0)R(r)$ decays, $\hat{\lambda}_{(+)}=\exp(+k_0x^0)R(r)$ exponentially grows to nonlinearly interact with the environmental field missing in our present model. As a tentative quantum mechanical scenario, we conjecture the following possibility. First, we regard this pair of solutions as a particle-antiparticle pair of the Majorana field: one is going forward in time, and the other is going backward. The reason why we can have such a pair is that the Clebsch dual electromagnetic field $S_{\mu\nu}$ has a simple bivector structure of the form Equation (17). If their spin axes are antiparallel, then the particle-antiparticle pair would combine as a boson to form an (spin 0) electric field, and if they are parallel, then we would have a (spin 1) magnetic field. Here, we regard this state change from two independent timelike Majorana fields produced by a point-like perturbation to a combined bosonic field as an internal field interaction. In addition, we further assume that the solution $R(r)$ given by Equation (27) is quantized such that $(\hat{\kappa}_r)^2=(n\kappa_0)^2$, where n denotes a positive integer. This quantization defines the discrete energy levels of the DP and the upper limit of the size of the DP explained in section 2.

5. Toward the integration of visible and invisible fields

As we have mentioned at the end of introductory section 1, a novel vision of cosmology, particularly regarding dark energy, arising from DP studies is what we least expected. A source-free Maxwell equation of electromagnetism

(in four-dimensional spacetime) and the de Sitter solution (closely related to the spacelike KG equation explained in subsection 4.1) in cosmology share the same characteristic of self-similarity, namely, they are scale independent. We think that self-similarity must be a key factor that connects a DP as a nanoscale entity with dark energy in cosmology. In concluding this article on a novel nanoscience perspective, we think that touching on such an unexpected finding demonstrating the vast potential of nanoscience to be explored is quite appropriate. In what follows, we first briefly refer to our recent studies [58] on dark energy and matter as a concrete example of the integration of visible and invisible fields and then extend our discussion to include the problem of consciousness, which would be the final frontier of the physical sciences.

In retrospect, our new proposal on the dark energy model is quite simple once we accept the notion of a Clebsch dual electromagnetic field giving the spacelike momentum field for quantum field interactions. In the preceding subsection 4.2, we have referred to Equation (26) showing how a bosonic Clebsch dual field can be constructed from the fermionic Majorana field. Recall that the reason why we introduce the Clebsch dual field is that the GR theorem explained in subsection 3.3 requires such a field for quantum field interactions. In this respect, we can say that, conceptually, the Clebsch dual field plays the role of virtual photons in the conventional QED. Since the spatial dimension of our universe is three, the maximum number of momentum vectors satisfying Equation (26) is also three. Namely, we have

$$M_{\mu\nu}\,p^{\nu} = N_{\mu\nu}q^{\nu} = L_{\mu\nu}r^{\nu} = W_{\mu}. \tag{29}$$

A Clebsch dual field arises from any pair of $[(p^{\mu}, q^{\mu}), (q^{\mu}, r^{\mu}), (r^{\mu}, q^{\mu})]$, each of which can be regarded as a "virtual photon field" moving along one direction of (x^1, x^2, x^3). Quantum mechanically, since the Clebsch dual field is composed of a Majorana field, the state represented by Equation (29) is the compound Rarita-Schwinger state of the Majorana field with spin 3/2.

The important role played by this compound state is as follows. We can regard this state $\left|M3\right\rangle_g$ as the "ground" state of the "virtual photon field". Since electromagnetic field interactions are ubiquitous phenomena in the universe, incessant occurrences of excitation-deexcitation processes between the ground $\left|M3\right\rangle_g$ and nonground states occur, which would make $\left|M3\right\rangle_g$ a "stable unseen off-shell state" from the viewpoint of a macroscopic time scale although the states of virtual photons are extremely ephemeral. At the end of subsection 4.1, we noted that the energy-momentum tensor $\hat{T}_{\mu}{}^{\nu}$ of the Clebsch dual field is isomorphic to the Einstein tensor $G_{\mu\nu}$ which facilitates obtaining $\left|M3\right\rangle_g$ in the theory of general relativity. Recall that $\hat{T}_{\mu}{}^{\nu}$ is itself a spacelike unobservable quantity. However, by referring to the fundamental knowledge of QFT regarding observable quantities explained in relation to Equation (1), we conjecture that the trace of $\hat{T}_{\mu}{}^{\nu}$ is an observable quantity since, by the abovementioned isomorphism, it is proportional to the scalar curvature R of the spacetime as the invariant of general coordinate transformation. The most well-known model of dark energy is what we call the cosmological term $\lambda g_{\mu\nu}$, and the value of λ derived by Planck satellite observations [65] is $\lambda_{\text{obs}} \approx 3.2 \times 10^{-53}$ m^{-2}. Although our model $\hat{T}_{\mu}{}^{\nu}$ is quite different from $\lambda g_{\mu\nu}$, we can define a reduced cosmological constant λ_{DP} as the trace of $\hat{T}_{\mu}{}^{\nu}$ and the λ_{DP} estimated by the DP experiments explained in subsection 2.2 turns out to be $\lambda_{DP} \approx 2.47 \times 10^{-53}$ m^{-2}, which is very close to λ_{obs}.

Regarding the physical meaning of the cosmological term $\lambda g_{\mu\nu}$, the long-standing controversy since the time of Einstein has not yet been settled. We think that the major problem is the fact that metric tensor $g_{\mu\nu}$ by itself is not an appropriate set of quantities to represent the gravitational field since for the flat spacetime, we can introduce a multitude of metric tensors depending on the coordinate system we choose. Our proposal for resolving this problem is to use the following identity [63] on Weyl curvature tensor $W_{\alpha\beta\gamma\delta}$:

$$W_{\mu\alpha\beta\gamma}W_{\nu}{}^{\alpha\beta\gamma} - \frac{1}{4}g_{\mu\nu}W^2 = 0, \ \ W^2 := W_{\alpha\beta\gamma\delta}W^{\alpha\beta\gamma\delta}. \tag{30}$$

Based on this identity, we can redefine metric tensor $g_{\mu\nu}$ as

$$g_{\mu\nu} := \frac{4W_{\mu\alpha\beta\gamma}\, W_{\nu}^{\ \alpha\beta\gamma}}{W^2},\qquad(31)$$

under the condition that $W^2 \neq 0$. Then, the cosmological term $\lambda g_{\mu\nu}$ with a certain meaningful constant λ becomes the energy-momentum tensor of the conformal gravitational field, of which justification in relation to the novel definition of entropy introduced by Aoki et al. [66] is given in the latest paper by Sakuma et al. [58].

The crucial assumption of $W^2 \neq 0$ is closely related to our novel cosmology, which is similar to conformal cyclic cosmology (CCC) proposed by Penrose [67]. The essential characteristic of CCC is that the universe repeats an infinite cycle of life and death through the interaction of the nodal "null universe" with a conformal light field. The decisive difference between our cosmology and CCC lies in the fact that while the twins (as a matter and antimatter pair) in the augmented universe play key roles in the former scenario, a single universe undergoes a cyclic process through its internal dynamics in the latter scenario. In our model, the creation and annihilation of twin universes can be compared to the pair creation and annihilation of elementary particles, and the configuration of twin universes in a 5-dimensional Minkowski space is uniquely determined by the dark energy field in our model [68]. In Figure 6, we give a schematic diagram showing how twin universes undergo everlasting cyclic changes.
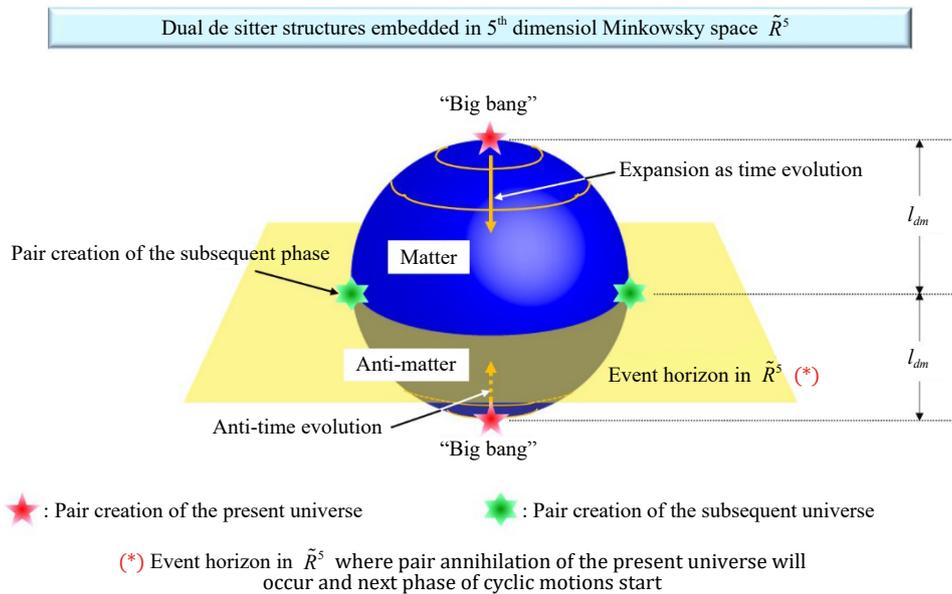
Figure 6. Schematic diagram on the infinite cyclic motions of twin universes. Twin material universes are born from the nodal "null universe" with conformal light field and will return to its original light field eons later by the process of a pair annihilation at the event horizon $\tilde{R}^5$.

In our new model, the abovementioned nodal null universe is represented by light fields that consist of the light field we are familiar with and the Clebsch dual light field of category I. In our cosmological scenario, the transition from the nodal null universe to the metric twin universes occurs as the result of simultaneous conformal symmetry breaking (SCSB) of electro-magnetic and gravitational fields. By SCSB of the electromagnetic field, we mean the appearance of the Clebsch dual light field of category II leading to the dark energy field λ_{DP}, and SCSB of the gravitational field corresponds to the emergence of a nonzero W^2 field in Equation (30). In their latest study on cosmology, Sakuma et al. [58] further showed that there exists a strong correlation between Weyl curvature tensor $W_{\alpha\beta\gamma\delta}$ and the gravitational entropy field having the form of a spin network, from which an intriguing dark matter model emerges.

Regarding the problem of fixing a constant for the cosmological term $\lambda g_{\mu\nu}$, they argue that the choice of

$$\lambda_{dm} := -\frac{1}{3}\lambda_{DP} > 0, \quad \lambda_{DP} \approx -2.47 \times 10^{-53}\,\mathrm{m}^{-2}, \tag{32}$$

would be an appropriate estimate consistent with the observational evidence that the abundance ratio between dark matter and dark energy is approximately 1:3. The reason why we have negative λ_{DP} here is because we employ the sign convention $(+ - - -)$ for metric tensor $g_{\mu\nu}$. Since the abundance ratio of ordinary matter is approximately 5 percent, the overall spacetime structure must be determined by dark matter and energy. We conjecture that Equation (32) reflects a formal equipartition of spacetime energy of the form

Dark matter $\Longrightarrow (\lambda_{dm}, 0, 0, 0)$
Dark energy $\Longrightarrow (0, -\lambda_{dm}, -\lambda_{dm}, -\lambda_{dm})$

from which we can say that our universe has a nearly flat spacetime structure.

In addition, as we have shown in Figure 6, the parameter $l_{dm} := \sqrt{(\lambda_{dm})^{-1}}$ gives the characteristic length scale of our universe. Immediately after the SCSB event, the magnitude of the emergent W^2 would be quite small. However, the local maxima of W^2 work as the cores of universal gravitation, so such cores become the seeds of galactic formation. Note that the smallness of W^2 means that the spacetime structure of the early universe was isotropic, so contrary to the widely prevalent theory based on a cosmic inflation scenario, our new theory naturally explains the isotropy of the early universe.

As we have explained in the arguments developed thus far, the essential ingredient of invisible fields is the spacelike momentum field breaking the Einstein causality. Although the GR theorem referred to in subsection 3.3 does not seem to attract the attention of mainstream physicists, we think that a currently spotlighted research theme such as quantum entanglement must be closely related to it. In subsection 4.1, we showed that DP constant $l_{dp} = (\kappa_0)^{-1}$ is a key parameter for spacelike momentum of electromagnetic field (cf. Equation (15)). One of the quite intriguing findings from the viewpoint of nanoscience is that DP constant $l_{dp} \approx 50$ nm gives the geometric mean of the smallest Planck length l_p and the largest characteristic length scale of our universe $l_{dm} = \sqrt{(\lambda_{dm})^{-1}}$, where λ_{dm} is given by Equation (32). Namely, l_{dp} is considered as "the central scale of our universe" called Heisenberg cut dividing our micro and macro universes, and our newly proposed model on DP genesis shows that DPs come into existence through the interactions between the visible materialistic field and the invisible spacelike momentum of electromagnetic field.

The final remarks we would like to make on the invisible spacelike momentum field that would connect every component in our universe instantaneously are its relationship with elusive consciousness. Presumably, an emerging view on this problem currently in the spotlight would be a notion called "singularity" of artificial intelligence (AI) [69]. According to this view, the singularity is loosely defined as the critical point in AI evolution beyond which AI will outperform human even in the realm of creativity. However, we should not miss the fact that a world-renowned mathematical physicist Penrose strongly disagrees with the existence of AI singularity. In one of his books entitled Shadows of the Mind [70], Penrose eloquently argues that, on the basis of Gödel's incompleteness theorems published for the second Hilbert problems [71], the activities of human consciousness including those of mathematics cannot be reduced to algorithmic processes on which AI essentially depends.

We can say that views on human consciousness conflicting with AI singularity are shared by not a few scientists and philosophers even in the western community. Hungarian philosopher of science László [72], the founder of the Club of Budapest, holds a unique view that the western science and the eastern esoteric philosophy can be united harmoniously. The following arguments on human consciousness we are going to develop are in line with such a basic philosophy of László. Since the electromagnetic field is an inevitable mediator for the normal operation of cranial nerve systems, we think assuming that conscious activities are related to such an invisible spacelike electromagnetic field is quite natural, especially when we consider the possible existence of what we call paranormal (or Psi) phenomena (PP), such as clairvoyance, telepathy and near-death experience (NDE). In modern societies where our sense of values has been heavily influenced by materialism, we tend to regard such PP as fantasies or hallucinations. However, there exist numerous scientific reports supporting their credibility [73], including a special report in which Alexander, a highly trained neurosurgeon at Harvard, described his own NDE [74] in detail as a bona fide challenge to the prevailing Western materialistic world view. We think that such an emerging societal situation in which we have conflicting world

views is, in a sense, similar to the situation we touched on in section 1, where we have two conflicting explanations of the existence of a longitudinal mode of an electromagnetic wave: the one based on fragmented knowledge, although it belongs to scientifically "advanced" QED, where a longitudinal mode is excluded as a ghost mode, and the other based on the quite sound but undistinguished scientific approach.

In coping with the problem of consciousness, the most difficult aspect of it would be how to deal with qualitative attribute such as motivation in life, selfish and unselfish acts, in addition to the interpretation of what we call mysterious experiences including inspiration, which is surely beyond the scope of the present physical sciences. Of course, now we do not have a clear vision on the way we should go, but we should bear in mind that, if we look back at the history of science, we find numerous stories in which inspirational experiences beyond description played a central role in making breakthrough achievements. In his autobiography [75], Nikola Tesla, a legendary genius in electrical engineering, tells us such an inspirational experience on the revolutionary idea of induction motor, which came suddenly to him as a "revelation" when he was reciting a verse of the "Sunset Speech" from Goethe's Faust. It seems that he could directly access to the blueprint for future technology by resonating with the currently unknown field beyond spacetime.

We think that, as the well-known Fourier analysis shows, if everything is composed of a certain energetic wave field, then the resonance may be interpreted as frequency matching. As Tesla's experience implies, such a frequency matching may be the ultimate way to learn the innermost secret of reality. In this respect, a medical practice such as wave adjustment therapy taken as a kind of pseudoscience may turn out to be a natural and sensible therapy. If we turn our eyes toward economic activities that are of vital importance to our societies, as in the case of medical care, we find that economics has reached an impasse over the question of how to deal with human factors such as motivation in life, selfish and unselfish acts already mentioned just before the anecdote of Tesla. In economics, the action of (self-interested) individual is simply modeled to maximize utility (function) as a measure of consumption. This oversimplification seems to be a modeling effort in pursuit of the formality of mathematical science and, by virtue of this, economics became the queen of social sciences. However, we can say that this very aspect of economics led to the unwanted degradation of economics in the sense that the model prediction does not reflect the real economic activities.

To overcome this drawback, Okabe [76] has launched an ambitious initiative called Humanomics as an investigation of the new form of economics in which the well-being (as a qualitative human factor) of constituent members in our communities and economic development (as a gross quantitative factor of macro-economics) are to be achieved in a consistent fashion. We think that the challenging endeavor of Humanomics is closely related to our main theme of consistent integration of different fields mentioned in section 1. In Okabe's proposal, an individual human is no longer a self-interested person, but a practitioner carving a new life of the self-improvement with the awareness that we are souls contributing to the harmonious development of our world. One of the fundamental premises of Humanomics is based on an unprecedented system of wisdom learning on the human existence established through a decades-long pilot study project. The whole project was led by Takahashi [77, 78], an eminent leader who is conversant with the wide spectrum of PP Alexander experienced and was supported by the active participation of numerous collaborators in the fields of medical practice, management, education, etc.

Our research on DPs initiated by the third author M. O. has been a continuous challenge of breaking the firmly established framework (or paradigm) of the existing theory of electromagnetism. Especially in the early stages, Ohtsu's DP research was considered quite abnormal such that almost all senior researchers in the field of optics ignored it. Concerning the dauntless challenging spirit of M. O., the first author H. S. thinks that Hancock [79], a British investigative journalist and bestselling writer who has been providing many thought-provoking ideas on the lost civilization of Atlantis, seems to share a similar challenging spirit. According to Hancock, his attempt to find evidence of the lost civilization was ridiculed by scientific communities in the 20th century. However, the situation has gradually changed with the accumulation of new archaeological evidence, especially recent quite convincing geophysical evidence of the catastrophic Younger Dryas event [80] reported in the Proceedings of the National Academy of Sciences, which confirms the period of the sudden fall of Atlantis told by Plato. Hancock speculates that Atlanteans did not have much interest in materialistic worlds compared to nonmaterialistic spiritual worlds because they knew that the former occupy extremely small portions of the entire world, just as our lifetime span on the earth is negligibly small compared to the eternal life of the spirit. Interestingly, such a world view of Atlanteans speculated by Hancock is exactly the same as what Alexander experienced in his NDE.

Suppose that souls are actually eternal entities experiencing infinite cycles of birth and death between the visible

and invisible worlds, as in the case of twin universes in our cosmology; then, we can say that the existence of DPs and the associated cosmology symbolize not only human existence but also Hancock's favorite Hermetic verse of "As above, so below". We believe that nanoscience will play the central role of a springboard in inducing a large paradigm shift in science.

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Conflict of interest

The authors declare no conflict of interest.

References

[1] Ohtsu M. *Dressed photons*. Berlin: Springer; 2014. p.89-214. Available from: https://doi.org/10.1007/978-3-642-39569-7.

[2] Ohtsu M. From classical to modern near-field optics and the future. *Optical Review*. 2014; 21: 905-910. Available from: https://doi.org/10.1007/s10043-014-0143-5.

[3] Cicchitelli L, Hora H, Postle R. Longitudinal field components for laser beams in vacuum. *Physical Review A*. 1990; 41(7): 3727-3732. Available from: https://doi.org/10.1103/physreva.41.3727.

[4] Nakanishi N, Ojima I. (eds.) *Covariant operator formalism of gauge theories and quantum gravity*. Singapore: World Scientific; 1990. Available from: https://doi.org/10.1142/0362.

[5] Ojima I. A unified scheme for generalized sectors based on selection criteria: Order parameters of symmetries and of thermality and physical meanings of adjunctions. *Open Systems and Information Dynamics*. 2003; 10(3): 235-279. Available from: https://doi.org/10.1023/A:1025175907589.

[6] Ojima I. Micro-macro duality in quantum physics. In: Hida T. (ed.) *Stochastic Analysis: Classical and Quantum - Perspectives of White Noise Theory*. Singapore: World Scientific; 2005. p.143-161. Available from: https://doi.org/10.1142/9789812701541_0012.

[7] Ohtsu M. Off-shell application in nanophotonics. Amsterdam: Elsevier; 2021. p.1-17. https://doi.org/10.1016/C2020-0-02956-7.

[8] Sangu S, Kobayashi K, Ohtsu M. Optical near fields as photon-matter interacting systems. *Journal of Microscopy*. 2001; 202(2): 279-285. Available from: https://doi.org/10.1111/j.1365-2818.2001.00805.x.

[9] Naruse M, Leibnitz K, Peper F, Tate N, Nomura W, Kawazoe T, et al. Autonomy in excitation transfer via optical near-field interactions and its implications for information networking. *Nano Communication Networks*. 2011; 2(4): 189-195. Available from: https://doi.org/10.1016/j.nancom.2011.07.002.

[10] Kawazoe T, Kobayashi K, Takubo S, Ohtsu M. Nonadiabatic photodissociation process using an optical near field. *The Journal of Chemical Physics*. 2005; 122(2): 024715. Available from: https://doi.org/10.1063/1.1828034.

[11] Ohtsu M. History, current developments, and future directions of near-field optical science. *Opto-Electronic Advances*. 2020; 3(3): 190046. Available from: https://doi.org/10.29026/oea.2020.190046.

[12] Ohtsu M. *Silicon light-emitting diodes and lasers*. Cham: Springer; 2016. Available from: https://doi.org/10.1007/978-3-319-42014-1.

[13] Ohtsu M. Progress in dressed photon technology and the future. In: Ohtsu M, Yatsui T. (eds.) *Progress in Nanophotonics 4*. Cham: Springer; 2017. p.1-18. Available from: https://doi.org/10.1007/978-3-319-49013-7_1.

[14] Kawazoe T, Ohtsu M, Aso S, Sawado Y, Hosoda Y, Yoshizawa K, et al. Two-dimensional array of room-temperature nanophotonic logic gates using InAs quantum dots in mesa structures. *Applied Physics B*. 2011; 103:

537-546. Available from: https://doi.org/10.1007/s00340-011-4375-9.

[15] Kawazoe T, Tanaka S, Ohtsu M. Single-photon emitter using excitation energy transfer between quantum dots. *Journal of Nanophotonics*. 2008; 2(1): 029502. Available from: https://doi.org/10.1117/1.3026554.

[16] Naruse M, Holmström P, Kawazoe T, Akahane K, Yamamoto N, Thylén L, et al. Energy dissipation in energy transfer mediated by optical near-field interactions and their interfaces with optical far-fields. *Applied Physics Letters*. 2012; 100(24): 241102. Available from: https://doi.org/10.1063/1.4729003.

[17] Naruse M, Tate N, Aono M, Ohtsu M. Information physics fundamentals of nanophotonics. *Reports on Progress in Physics*. 2013; 76(5): 056401. Available from: https://doi.org/10.1088/0034-4885/76/5/056401.

[18] Kim SJ, Naruse M, Aono M, Ohtsu M, Hara M. Decision maker based on nanoscale photo-excitation transfer. *Scientific Reports*. 2013; 3: 2370. Available from: https://doi.org/10.1038/srep02370.

[19] Aono M, Naruse M, Kim SJ, Wakabayashi M, Hori H, Ohtsu M, et al. Amoeba-inspired nanoarchitectonic computing: Solving intractable computational problems using nanoscale photoexcitation transfer dynamics. *Langmuir*. 2013; 29(24): 7557-7564. Available from: https://doi.org/10.1021/la400301p.

[20] Kawazoe T, Kobayashi K, Ohtsu M. Near-field optical chemical vapor deposition using $Zn(acac)_2$ with a non-adiabatic photochemical process. *Applied Physics B*. 2006; 84: 247-251. Available from: https://doi.org/10.1007/s00340-006-2224-z.

[21] Lim J, Yatsui T, Ohtsu M. Observation of size-dependent resonance of near-field coupling between a deposited Zn dot and the probe apex during near-field optical chemical vapor deposition. *IEICE Transactions on Electronics*. 2005; E88-C(9): 1832-1835. Available from: https://doi.org/10.1093/ietele/e88-c.9.1832.

[22] Polonski VV, Yamamoto Y, Kourogi M, Fukuda H, Ohtsu M. Nanometric patterning of zinc by optical near-field photochemical vapour deposition. *Journal of Microscopy*. 1999; 194(2-3): 545-551. Available from: https://doi.org/10.1046/j.1365-2818.1999.00497.x.

[23] Yonemitsu H, Kawazoe T, Kobayashi K, Ohtsu M. Nonadiabatic photochemical reaction and application to photolithography. *Journal of Luminescence*. 2007; 122-123: 230-233. Available from: https://doi.org/10.1016/j.jlumin.2006.01.115.

[24] Inao Y, Nakasato S, Kuroda R, Ohtsu M. Near-field lithography as prototype nano-fabrication tool. *Microelectronic Engineering*. 2007; 84(5-8): 705-710. Available from: https://doi.org/10.1016/j.mee.2007.01.043.

[25] Kawazoe T, Kobayashi K, Akahane K, Naruse M, Yamamoto N, Ohtsu M. Demonstration of nanophotonic NOT gate using near-field optically coupled quantum dots. *Applied Physics B*. 2006; 84: 243-246. Available from: https://doi.org/10.1007/s00340-006-2234-x.

[26] Kawazoe T, Takahashi T, Ohtsu M. Evaluation of the dynamic range and spatial resolution of nonadiabatic optical near-field lithography through fabrication of Fresnel zone plates. *Applied Physics B*. 2010; 98: 5-11. Available from: https://doi.org/10.1007/s00340-009-3680-z.

[27] Koike M, Miyauchi S, Sano K, Imazono T. X-ray devices and the possibility of applying nanophotonics. In: Ohtsu M. (ed.) *Nanophotonics and Nanofabrication*. Germany: Wiley-VCH; 2009. p.179-191.

[28] Hirata K. Realization of high-performance optical element by optical near-field etching. In: *Laser-based Micro- and Nanopackaging and Assembly V*. California, United States: SPIE; 2011. p.79210M. Available from: https://doi.org/10.1117/12.875808.

[29] Yatsui T, Nomura W, Ohtsu M. Realization of ultraflat plastic film using dressed-photon-phonon-assisted selective etching of nanoscale structures. *Advances in Optical Technologies*. 2015; 2015: 701802. Available from: https://doi.org/10.1155/2015/701802.

[30] Yatsui T, Hirata K, Tabata Y, Miyake Y, Akita Y, Yoshimoto M, et al. Self-organized near-field etching of the sidewalls of glass corrugations. *Applied Physics B*. 2011; 103: 527-530. Available from: https://doi.org/10.1007/s00340-011-4569-1.

[31] Teki R, Kadaksham AJ, House M, Harris-Jones J, Ma A, Babu SV, et al. Alternative smoothing techniques to mitigate EUV substrate defectivity. In: *Extreme Ultraviolet (EUV) Lithography III*. California, United States: SPIE; 2012. p.83220B. Available from: https://doi.org/10.1117/12.916497.

[32] Yatsui T, Nomura W, Stehlin F, Soppera O, Naruse M, Ohtsu M. Challenges in realizing ultraflat materials surfaces. *Beilstein Journal of Nanotechnology*. 2013; 4: 875-885. Available from: https://doi.org/10.3762/bjnano.4.99.

[33] Nomura W, Yatsui T, Yanase Y, Suzuki K, Fujita M, Kamata A, et al. Repairing nanoscale scratched grooves on polycrystalline ceramics using optical near-field assisted sputtering. *Applied Physics B*. 2010; 99: 75-78. https://doi.org/10.1007/s00340-009-3797-0.

[34] Yatsui T, Nomura W, Naruse M, Ohtsu M. Realization of an atomically flat surface of diamond using dressed photon–phonon etching. *Journal of Physics D: Applied Physics*. 2012; 45(47): 475302. Available from: https://doi.org/10.1088/0022-3727/45/47/475302.

[35] Hirschman KD, Tsybeskov L, Duttagupta SP, Fauchet P. Silicon-based visible light-emitting devices integrated into microelectronic circuits. *Nature*. 1996; 384: 338-341. Available from: https://doi.org/10.1038/384338a0.

[36] Lu ZH, Lockwood DJ, Baribeau JM. Quantum confinement and light emission in SiO_2/Si superlattices. *Nature*. 1995; 378: 258-260. Available from: https://doi.org/10.1038/378258a0.

[37] Kawazoe T, Mueed MA, Ohtsu M. Highly efficient and broadband Si homojunction structured near-infrared light emitting diodes based on the phonon-assisted optical near-field process. *Applied Physics B*. 2011; 104: 747-754. Available from: https://doi.org/10.1007/s00340-011-4596-y.

[38] Yamaguchi M, Kawazoe T, Ohtsu M. Evaluating the coupling strength of electron–hole pairs and phonons in a 0.9 μm-wavelength silicon light emitting diode using dressed-photon–phonons. *Applied Physics A*. 2014; 115: 119-125. Available from: https://doi.org/10.1007/s00339-013-7904-z.

[39] Ohtsu M, Kawazoe T. Principles and practices of Si light emitting diodes using dressed photons. *Advanced Materials Letters*. 2019; 10(12): 860-867. Available from: https://doi.org/10.5185/amlett.2019.2264.

[40] Tanaka Y, Kobayashi K. Optical near field dressed by localized and coherent phonons. *Journal of Microscopy*. 2008; 229(2): 228-232. Available from: https://doi.org/10.1111/j.1365-2818.2008.01891.x.

[41] Kawazoe T, Nishioka K, Ohtsu M. Polarization control of an infrared silicon light-emitting diode by dressed photons and analyses of the spatial distribution of doped boron atoms. *Applied Physics A*. 2015; 121: 1409-1415. Available from: https://doi.org/10.1007/s00339-015-9288-8.

[42] Wada N, Kawazoe T, Ohtsu M. An optical and electrical relaxation oscillator using a Si homojunction structured light emitting diode. *Applied Physics B*. 2012; 108: 25-29. Available from: https://doi.org/10.1007/s00340-012-5100-z.

[43] Sakuma H, Ojima I, Ohtsu M, Kawazoe T. Drastic advancement in nanophotonics achieved by a new dressed photon study. *Journal of the European Optical Society-Rapid Publications*. 2021; 17: 28. Available from: https://doi.org/10.1186/s41476-021-00171-w.

[44] Hanbury Brown R, Twiss RQ. A test of a new type of stellar interferometer on Sirius. *Nature*. 1956; 178, 1046-1048. Available from: https://doi.org/10.1038/1781046a0.

[45] Wightman AS. On the localizability of quantum mechanical systems. *Reviews of Modern Physics*. 1962; 34(4): 845-872. Available from: https://doi.org/10.1103/RevModPhys.34.845.

[46] Tanaka H, Kawazoe T, Ohtsu M, Akahane K. Decreasing the threshold current density in Si lasers fabricated by using dressed-photons. *Fluorescent Materials*. 2015; 1(1): 1-7. Available from: https://doi.org/10.1515/fma-2015-0001.

[47] Kawazoe T, Hashimoto K, Sugiura S. High-power current-injection type silicon laser using nanophotonics. In: *EMN Meeting on Nanocrystals, 17-21 October 2016, Xi'an, China*. China: EMN; 2016. p.9-11.

[48] Aspect A, Grangier P, Roger G. Experimental tests of realistic local theories via Bell's theorem. *Physical Review Letters*. 1981; 47(7): 460. Available from: https://doi.org/10.1103/PhysRevLett.47.460.

[49] Einstein A, Podolsky B, Rosen N. Can quantum-mechanical description of physical reality be considered complete? *Physical Review*. 1935; 47(10): 777-780. Available from: https://doi.org/10.1103/PhysRev.47.777.

[50] Doplicher S, Haag R, Roberts JE. Fields, observables and gauge transformations I. *Communications in Mathematical Physics*. 1969; 13: 1-23. Available from: https://doi.org/10.1007/BF01645267.

[51] Doplicher S, Haag R, Roberts JE. Fields, observables and gauge transformations II. *Communications in Mathematical Physics*. 1969; 15: 173-200. Available from: https://doi.org/10.1007/BF01645674.

[52] Doplicher S, Roberts JE. Why there is a field algebra with a compact gauge group describing the superselection structure in particle physics. *Communications in Mathematical Physics*. 1990; 131(1): 51-107. Available from: https://doi.org/10.1007/BF02097680.

[53] Nambu Y, Jona-Lasinio G. Dynamical model of elementary particles based on an analogy with superconductivity. I. *Physical Review*. 1961; 122(1): 345-358. Available from: https://doi.org/10.1103/physrev.122.345.

[54] Lehmann H, Symanzik K, Zimmermann W. Zur formulierung quantisierter feldtheorien. *Il Nuovo Cimento*. 1955; 1: 205-225. Available from: https://doi.org/10.1007/bf02731765.

[55] Streater RF, Wightman AS. *PCT, spin and statistics, and all that*. Princeton: Princeton University Press; 1964.

[56] Dell'Antonio GF. Support of a field in *p* space. *Journal of Mathematical Physics*. 1961; 2(6): 759-766. Available from: https://doi.org/10.1063/1.1724219.

[57] Jost R. *The general theory of quantized fields*. Providence, RI, USA: American Mathematical Society; 1965.

[58] Sakuma H, Ojima I, Saigo H, Okamura K. Conserved relativistic Ertel's current generating the vortical and thermodynamic aspects of space–time. *International Journal of Modern Physics A*. 2022; 37(22): 2250155. Available from: https://doi.org/10.1142/s0217751x2250155x.

[59] Bers A, Fox R, Kuper CG, Lipson SG. The impossibility of free tachyons. In: Kuper CG, Peres A. (eds.) *Relativity*

and Gravitation. New York, USA: Gordon and Breach Science Publishers; 1971.

[60] Lamb H. *Hydrodynamics*. 6th ed. Cambridge: Cambridge University Press; 1930. p.248-249.

[61] Sakuma H, Ojima I, Ohtsu M. Dressed photons in a new paradigm of off-shell quantum fields. *Progress in Quantum Electronics*. 2017; 55: 74-87. Available from: https://doi.org/10.1016/j.pquantelec.2017.07.006.

[62] Sakuma H. Virtual photon model by spatio-temporal vortex dynamics. In: Yatsui T. (ed.) *Progress in Nanophotonics 5*. 2018. Cham: Springer; 2018. p.53-77. Available from: https://doi.org/10.1007/978-3-319-98267-0_2.

[63] Sakuma H, Ojima I, Ohtsu M, Ochiai H. Off-shell quantum fields to connect dressed photons with cosmology. *Symmetry*. 2020; 12(8): 1244. Available from: https://doi.org/10.3390/sym12081244.

[64] Aharonov Y, Komar A, Susskind L. Superluminal behavior, causality, and instability. *Physical Review*. 1969; 182(5): 1400-1403. Available from: https://doi.org/10.1103/physrev.182.1400.

[65] @Hongwan Liu. The cosmological constant is measured as the dimensionless quantity. [cited 2013 December 24.] https://www.quora.com/What-is-the-best-estimate-of-the-cosmological-constant/answer/Hongwan-Liu [Accessed 24th February 2019]

[66] Aoki S, Onogi T, Yokoyama S. Charge conservation, entropy current and gravitation. *International Journal of Modern Physics A*. 2021; 36(29): 2150201. Available from: https://doi.org/10.1142/s0217751x21502018.

[67] Penrose R. Before the big bang: an outrageous new perspective and its implications for particle physics. In: *Proceedings of EPAC 2006*. Edinburgh, Scotland: EPAC; 2006. p.2759-2762. Available from: https://accelconf.web.cern.ch/e06/PAPERS/THESPA01.PDF.

[68] Sakuma H, Ojima I. On the dressed photon constant and its implication for a novel perspective on cosmology. *Symmetry*. 2021; 13(4): 593. Available from: https://doi.org/10.3390/sym13040593.

[69] Kurzweil R. *The singularity is near: When humans transcend biology*. New York: Viking Penguin; 2005.

[70] Penrose R. *Shadows of the mind*. Oxford: Oxford University Press; 1994.

[71] Simons Foundation. *Hilbert's problems: 23 and math*. https://www.simonsfoundation.org/2020/05/06/hilberts-problems-23-and-math/ [Accessed 16th December 2022].

[72] László E. *Ervin Laszlo*. https://ervinlaszlobooks.com/ [Accessed 21st December 2022].

[73] Kelly EF, Kelly EW, Crabtree A, Gauld A, Grosso M, Greyson B. *Irreducible mind: Toward a psychology for the 21st century*. Lanham: Rowman & Littlefield; 2007.

[74] Alexander E. *Proof of heaven: A neurosurgeon's journey into the afterlife*. New York: Simon & Schuster; 2012.

[75] Tesla N. *My inventions: The autobiography of Nikola Tesla*. New York: Experimenter Publishing Company, Inc.; 1919.

[76] Okabe M. *Humanomics: Exploring economics based on human nature (in Japanese)*. Tokyo, Japan: Nippon Hyoronsha, 2022.

[77] Takahashi K. *The path of prayer: For a supreme dialogue*. Trans Ridley C. Tokyo, Japan: Sampoh Publishing Co., Ltd.; 2014.

[78] Takahashi K. *The soul doctrine as a way of life: 5 inner revolutions to change life and work*. Trans Brooks W. Tokyo, Japan: Sampoh Publishing Co., Ltd; 2017.

[79] Hancock G. *About the speaker, Graham Hancock*. https://www.alternatives.org.uk/event/ancient-apocalypse [Accessed 5th October 2022].

[80] Firestone RB, West A, Kennett JP, Becker L, Bunch TE, Revay ZS, et al. Evidence for an extraterrestrial impact 12,900 years ago that contributed to the megafaunal extinctions and the Younger Dryas cooling. *Proceedings of the National Academy of Sciences*. 2007; 104(41): 16016-16021. Available from: https://doi.org/10.1073/pnas.0706977104.