

► **A Novel Simple Technique to Study Mie Scattering  
Imaging with Photon Counts: Introduction  
and Its Applications**

*Nanotechnology philosophy*

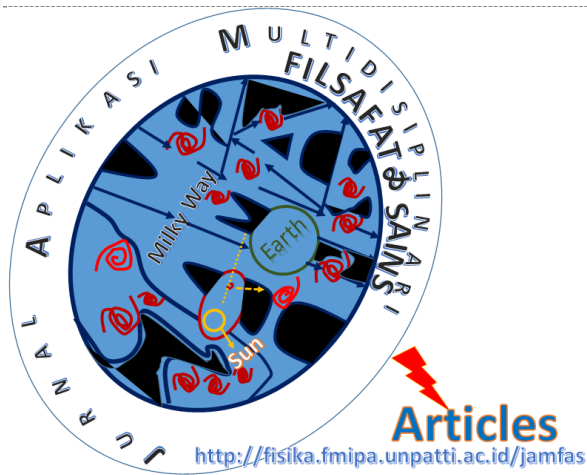
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**Abstract**

In this paper, we propose a novel simple technique by combining the experimental bright-field imaging, Rayleigh or Mie scattering, and photon counts in order to investigate and distinguish the light scattering from nanohybrid polymer materials and its aggregation imaging. In particular, by studying the imaging of nanohybrid polymer and measuring its photon counts, we can demonstrate how big the different of photon counts of each images of nanohybrid polymer materials. Moreover, by combining bright-field imaging with its photon counts in the framework of the generalized scattering theory, we show that this nanohybrid polymer exhibits the scattering differently based on the number of nanoparticles or aggregations. This novel technique can be widely applied in many different research works such as nanomedicine and nanotechnology.

**Keywords:** *Novel technique, Mie scattering, Nanohybrid materials, Photon counts.*

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## A Novel Simple Technique to Study Mie Scattering Imaging with Photon Counts: Introduction and Its Applications

### I. INTRODUCTION

In this 21<sup>st</sup> Century, the most sophisticated technology that can be able to be applied widely in the whole earth is nanotechnology. Light-matter interactions are the front field to achieve great contributions for daily life of various societies. There are many types of methods have been developed to discover more novel optical, electronics and their integrated links in a smart nanodevice such as nanofiber laser, nanosensors, and nanomachines that can be moved inside living things including

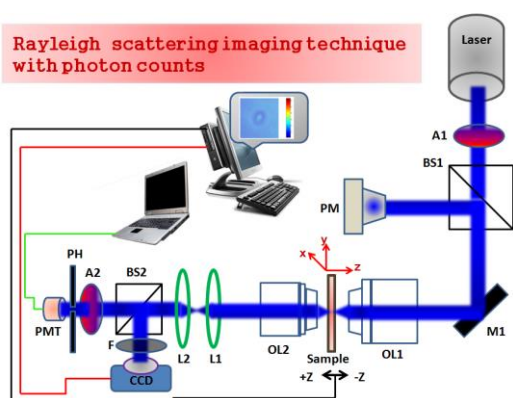
inside human bloods [1-20]. Furthermore, the only technology that human kind can imitate and learn is the living laboratory or natural laboratory made by the creator hand. You can imagine how modern the human device or works, but it cannot be comparable with the giant Creator (God Himself).

In this paper, we try to present our novel simple technique to study how big the light (photon) mainly focused on a certain size of particles can be detected based on sizes of the aggregations of nanohybrid particles. This scattering is called as Mie scattering. From our results, we obtain significantly that the bigger the aggregation, the larger number of photon counting which contributes to the development of telecommunication devices and systems.

### II. EXPERIMENTAL PROCEDURE

The experimental setup of Rayleigh or Mie scattering imaging with photon counts technique is proposed and shown in **Fig. 1** and its physical application in nanomedicine as shown in our former work in **Ref. [21]**. An objective lens (**OL**) focuses a laser beam onto the sample, which can be moved along  $z$  direction or axis in order to adjust the focus

point and to  $xy$  directions to scan the distribution of particles, and another **OL** with higher numerical aperture (**NA**) is placed in front of the sample in order to collect the image of the nanostructure. The image of the sample is then captured by a high resolution charge couple device (**CCD**) camera and the photon counts of nanohybrid polymer due to the interaction of the sample and laser light is simultaneously recorded by a photomultiplier tube (**PMT**) controlled by a computer.



**Figure 1.** The experimental setup of Rayleigh or Mie scattering imaging with photon counts. A, BS, PM, M, OL, L, F, PH and PMT stand for attenuator, beam splitter, power meter, mirror, objective lens, lens, filter, pinhole, and photomultiplier tube, respectively [21].

This Rayleigh or Mie scattering imaging with photon counts technique is actually a newly modified Rayleigh scattering imaging techniques<sup>1-5</sup> with additional photon counts of the particles. In our setup, we use a **continuous-wave (CW)**

laser with wavelength of  $\sim 407$  nm and a 0.85 NA objective lens (**OL2**) with its magnification and working distance are 20x and  $\sim 650$   $\mu\text{m}$ , respectively so that the resolution or diffraction limit ( $\lambda/2\text{NA}$ ) is  $\sim 240$  nm, which is small enough to study a single aggregation of nanohybrid polymer. The light scattering parameter of  $\alpha$  can be distinguished by the following well-known formula:<sup>6</sup>  $\alpha = \pi D/\lambda$ , where D is the diameter of particle,  $\alpha < 0.4$  is for Rayleigh scattering,  $0.4 < \alpha < 3$  is for Mie scattering, and  $\alpha > 3$  is for normal refraction. Therefore, from the highest resolution of our setup (in scale of  $\sim 240$  nm) we can study the Mie scattering of an aggregation of nanohybrid polymer materials.

In our experiment, we chose ZnO nanohybrid polymers among another metal oxide materials such as TiO<sub>2</sub>, SiO<sub>2</sub>, ZrO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> as our sample because it has various applications to optical components, such as micro-lens for CCD/CMOS image sensors, thin films and anti-reflective coatings for flat-panel displays (**LCD** and **OLED**), photovoltaic cells, field emission device, and waveguide circuits in optical interconnects and telecommunications [7-11]. The presence of polymer matrix in this nanohybrid material has advantages as follows: a) facile formation of thin films at lower

temperatures, b) light-weight, toughness, and flexibility, c) micro-patternability by photolithography or imprinting, d) wide range of molecular design, and e) facile incorporation of metallic or inorganic dopants or nano-particles [12-15]. In contrast, the drawbacks of polymeric materials are 1) low thermal stability, 2) high moisture absorption, 3) low environmental stability and durability, 4) narrow range of controllable optical properties such as transmittance, wavelength range with high transparency, refractive indices, birefringence, and thermo-optic coefficients, and 5) low thermal conductivity. Currently, with the rapid development of nanoscience and nanotechnology, nano-hybridization of polymers with metallic or inorganic nanoparticles becomes a promising technique to overcome the drawbacks without reducing their inherent advantages [16-18].

### III. RESULTS AND DISCUSSIONS

To utilize this setup, we chose a single aggregate or several aggregations of ZnO nanohybrid epoxy resin/polymer as our sample, because ZnO nanohybrid polymer

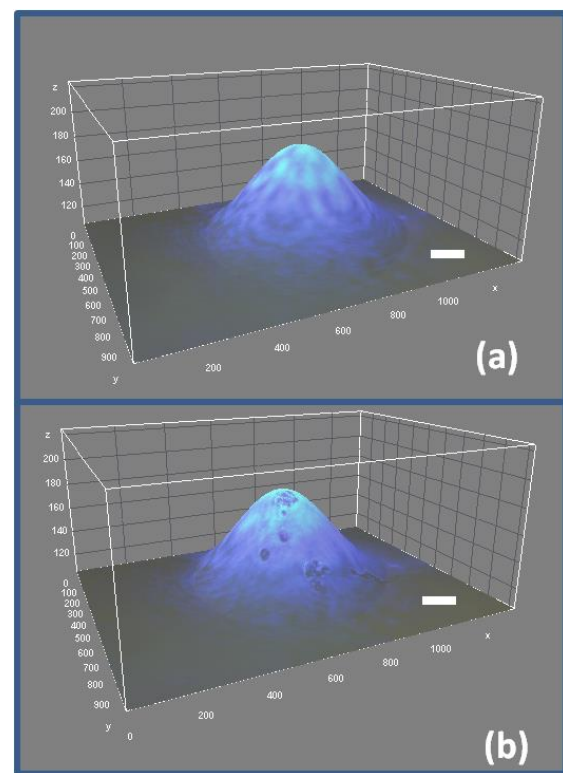
was easily prepared using milling and centrifuge process from Ref. [19] combined with pre-polymer process in Ref. [20]. Figure 3 depicted in Ref. [21] shows the transmittance spectrum of ZnO nanohybrid polymer with diameter of ZnO nanoparticles (from Nanostructured & Amorphous Materials, Inc. (NanoAmor), USA) ~20 nm assessed at visible wavelengths. We obtained that the transmittance and linear absorption coefficient,  $\alpha_0$  measured at 407 nm of this thin film is ~84% and  $2.2 \times 10^3 \text{ cm}^{-1}$ , respectively. The Mie scattering imaging with photon counts experiments were technically carried out by using the setup based on Fig. 1 with the power of laser source of 50  $\mu\text{W}$ . The OL1 employed has a 8.8 mm focal length, producing a focused beam with a beam waist of  $\omega_0 = \sim 8 \mu\text{m}$ . The thickness of the ZnO nanohybrid polymer film deposited on a glass substrate is  $\sim 0.16 \mu\text{m}$ , which is shorter than the Rayleigh range,  $z_0$  of the focused beam ( $z_0 = \pi\omega_0^2/\lambda = 770 \mu\text{m}$ ). To understand the physical origin of the Mie scattering induced by the aggregation of ZnO nanohybrid polymer, we compare four images and its photon counts, which show different number of particles or aggregations recorded at different  $xy$  position in the thin

film. The figure [21] demonstrated the two-dimensional (2D) images of the sample interacted with the laser light, as well as their average photon counts.

From these 2D images, the photon counts are increased as the number of aggregation or particles of ZnO nanohybrid polymer increase. This result is consistent and in reasonably good agreement with the theory of Rayleigh [19,20] or Mie scatterings [6], respectively. To study and analyze the intensity profile of each images observed at the focus point, we plotted a 3D image of the data as shown in Fig. 3 in Ref. [21], and analyzed its beam profile as depicted in Fig. 2 so that the profile of the interaction between laser beam and the sample observed when the sample at the focus point or  $z = 0$  is obviously appeared slightly reduced due to the intensity in the center of the beam profile. This is mainly due to the high linear absorption and Mie scattering of the aggregation of ZnO nanoparticles measured at 407 nm.

This Mie scattering is much stronger than the Rayleigh scattering of ZnO nanohybrid polymer and TiO<sub>2</sub> nanohybrid polymer [19,20]. Such properties of light scattering phenomena in a structure of nanoparticles aggregation provide a novel strategy for the realization of optical devices such as optical

waveguides and optical switching for telecommunication system in which it is not good for optical devices if there is a presence of aggregation in it. Further research work is needed particularly in improving Rayleigh scattering imaging with photon counts for particles smaller than one tenth of operating laser wavelength.



**Figure 2.** (a) The beam profile of the experimental setup taken without any sample. (b) The 3D image of Fig. 3(d) or the beam profile when there are some aggregations. In these images, z-axis is the intensity of the laser beam, and the bar scale is 3  $\mu\text{m}$ .

#### IV. CONCLUSION

In conclusion, we have successfully constructed a novel experimental setup by

combining bright-field imaging, Rayleigh or Mie scattering, and photon counts in order to investigate and distinguish the light scattering from nanohybrid polymer materials and its aggregation imaging. We have found that the number of photon counts is increased by the increase of the number of aggregation or particles in nanohybrid polymer. In addition, this setup can be used for  $z$  scan imaging technique, which so far has not been developed by any other researchers, by replacing PMT in **Fig. 1** with power meter or spectrometer. In this case, the sample can be moved in  $z$  direction and the transmittance and the image of the particles can be recorded by spectrometer or power meter and CCD simultaneously at each  $z$  positions.

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Short Biography of the **corresponding author:**

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**Hendry Izaac Elim, Ph.D: Young Indonesia Scientist 2017** (Rector letter dated on 13<sup>rd</sup> November 2017, No. 1157/UNI13/SK/2017) from Pattimura university (Ph.D.-Physics; personal website: <http://fisika.fmipa.unpatti.ac.id/hendry-izaac-elim> ), now is an experience Indonesia scientist of nanoscience and nanotechnology (rank 23<sup>rd</sup> in 2017 based on Webometrics (<http://www.webometrics.info/en/node/96> ), and the 45<sup>th</sup> best Indonesia scientist according to SINTA-RistekDikti in May 2018), head of the Nanotechnology Research Center and Innovative Creation (PPNRI-LPPM, website: <http://lppm.unpatti.ac.id/pusat-pnri> ) of the Pattimura University (UNPATTI), Chairman for Nanomaterials for Photonics Nanotechnology Laboratory (N4PN Lab), Physics Department, Faculty of Mathematics and Natural Sciences (FMIPA-UNPATTI), Ambon, Indonesia, and regular Member of the Indonesia Theoretical Physicist. He got his **B.Sc (S.Si) in Theoretical Physics in 1995 at Gadjah Mada university (UGM), the oldest university in Indonesia, M.Si (M.Sc) in Theoretical Physics of Institut Teknologi Bandung (ITB) in 1999, Specialist in nanoscience and nanotechnology, Physics Doctor's degree (Ph.D.) at National University of Singapore (NUS), Singapore on 13<sup>th</sup> December 2005, Docent at FMIPA-UNPATTI since 2000 up to present.** After his

PhD at NUS, Dr. Elim worked as a postdoctoral fellow in physics department of NUS, and about 2 years later He moved to Tohoku university, Sendai, Japan working as a research professor on superhybrid materials project at Institute of Multidisciplinary Research for Advanced Materials (IMRAM) from 2007 to 2012. In 2013, Dr. Elim worked as a scientist at Surya university, Indonesia for 3 months and then moved to STKIP Surya, Gading Serpong, Tangerang, Indonesia working as a physics lecturer for 1 year. Later in September 2014, Dr. Elim returned to FMIPA-UNPATTI and started building N4PN Lab as well as PPNRI-LPPM (URL: <http://lppm.unpatti.ac.id/pusat-pnri> ) until present time. The advancement of Science and technology development of Dr. Elim group started by educating the first 6 research B.Sc students and since that He already educated more than 50 graduated B.Sc in physics from all simple advanced research on novel superfibers fabricated from all types of garbage materials, new liquid energy fuel cells system, and nanomedicine of herbal drugs, respectively. The studies involved their mechanical, optical, and chemical properties as well as molecular electronic system. Recently, Dr. Elim is leading research on water contaminated by  $\text{CaCO}_3$ , the aggregation of salt behaviors in ocean water and energy research development and their relationships with herbal medicine extracted from fruits and leaves. Furthermore, Dr. Elim educated few research students to work on bio-membrane films and fibers fabricated using rubbish natural things. These studies involved their mechanical and optical behaviors. In addition, Dr. Elim had been recently invited to give international scientific talks as well as many quest lecture talks in many national universities such as UNPATTI, UNIMA, UNSRAT, STIKES Halmahera, AKBID MAKARIWO, and UI of Indonesia closely related to the multitasking applications of nanoscience and nanotechnology in small islands and human characters. In addition, Dr. Elim was invited to give a talk in a breakthrough international conference of pharmaceutical nanomedicine and nanotechnology in Las Vegas, USA in April 2018. Based on the international community data recorded in Web of Science, Dr. Elim have published over 50 papers with h-index of 24 (SCOPUS), and citation more than 2200. In addition, Dr. Elim is a member of top scientific society such as AAAS (ID No. 41737449) since 2017, and ACS (ID No. 31447106) in 2018. Dr. Elim was also awarded Saryalancana Karya Satya XX from President of Indonesia on 2<sup>nd</sup> May 2017 at Pattimura university.

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