Proposal for a New Artifact-Metrics Method (Application to Valuable Pottery, Porcelain and Glass Products)

Masaki Fujikawa, Fumihiko Oda, Kengo Moriyasu, Shingo Fuchi, and Yoshikazu Takeda

***Abstract*—The authors propose a new method in which the fact that a pottery or porcelain product is actually produced by the brand-holder company or by the ceramic artist (authenticity) can be easily verified, and at the same time, production of counterfeit products becomes difficult. The artifact-metrics are used in this method and as the material used in the method is transparent, the patterns and color tone created by the master artisan or ceramic artist are not affected. As the material is applied on to the product in the process of enameling or glazing, no additional work process is required for the master artisan or ceramic artist must take. Furthermore, because the method does not require UV rays or radioactive rays in registration and verification of products, potential hazards to the human body or product are eliminated, and no special skill is required in verification of authenticity. In this report, the authors indicate high feasibility of this method by showing results of elementary experiments.**

***Index Terms*—Artifact-metrics, authenticity verification, glass phosphor, infrared image processing.**

I. Introduction

Valuable pottery, porcelain, or glass products produced by renowned brands trade at high prices, and there are malicious persons trying to produce and sell counterfeit products [1]-[3], and such acts must not be ignored as in the case of counterfeit brand goods, such as bags and ornaments. Such acts not only violate the intellectual property rights of brand holders but violators gain an unfair amount of money by deceiving buyers.

As proof of authenticity of the products, brand holders of pottery, porcelain, and glass products engrave or paint their brand names or ID numbers on the shipped products. (For example, a porcelain producer engraves the brand name on the formed clay or hand paints ID numbers. A glass producer applies the brand name or ID number by etching or sand blasting.) However, because counterfeit products that imitate such brand names and ID numbers are produced and sold [4], [5], the above countermeasures are not decisive as proof of authenticity.

Generally, it is quite difficult to verify the authenticity of pottery, porcelain, and glass products in an expedient way, and it requires the experience, expertise, and skill of a person (i.e., connoisseur). Accordingly, there remains the risk of purchasing counterfeit products for resale purposes or selling counterfeit products as authentic without knowing it if the verification skill is not adequate. (There was actually a case where a named department store sold leather goods to customers as authentic products that were actually counterfeit products because the buyer failed to identify the fraud [6].)

The authors believe that the technology should be established that makes fabrication of counterfeit pottery, porcelain, and glass products difficult and verification of authenticity easy even without sophisticated skills as is the case for value-bearing paper like bank notes. Because the design (shape, surface colors, etc.) is essential in these products, the technology must not impair the design of the product and must not require additional work by the master craftsman or artisan. The authors invented the new artifact-metrics that can be applied for individual pottery, porcelain, and glass products produced every day, which is introduced in this paper.

In this report, discussions are made in the following order. In Section II, an outline of the proposed artifact-metrics is presented first, and the requirements and prerequisites used in this report are explained. In Section III, the proposed method is explained in detail. In Section IV, fundamental testing conducted to verify the proposed method and the results are discussed, and in Section V, discussions of this method are provided from the perspectives of security, convenience, cost, and social acceptance.

II. Preparations

A. What Artifact-Metrics Mean?

Artifact-metrics is a coined term combining “artifact” and “metrics” with the term “biometrics” as a reference, which is defined as “the technology used to authenticate the artifact making use of the peculiarities of such an artifact” [7]. While physical and/or behavioral peculiarities of a person are the criteria for authentication in biometrics, the characteristics (peculiarity information) that are incidentally created during production of the artifact are the criteria for the artifact. Authenticity of the artifact is determined by comparing the peculiarity information detected by the instrument with the peculiarity information registered beforehand, similar to biometrics.

The system incorporating artifact-metrics is called the Artifact-Metrics System, and the schematic diagram is shown in Fig. 1. Microscopically, peculiarity information differs for each individual artifact but it is not easy to extract such a peculiarity. Accordingly, the artisan frequently employs a

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technique to add a material to the artifact or use a specific method to extract peculiarity information suitable for such a material. For example in the case of reference [8], paper in which fine magnetic fibers (material) are woven is used for indenture documents (artifact), and the peculiarity information (magnetic signal) is extracted by scanning the document with a magnetic head.

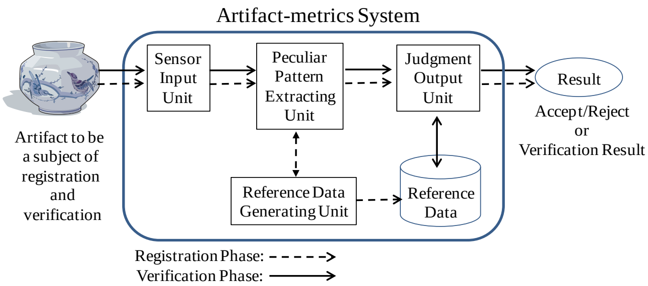

Fig. 1. Schematic diagram of artifact-metrics system.

B. Requirements of Artifact-Metrics

In this section, the requirements of the artifact-metrics proposed in this report are discussed. First, a material to be added to the artifact (pottery, porcelain, or glass products) to make extraction of the peculiarity information easier should not affect the color generated during firing by clay, glass, glaze, and paint and should not be harmful to human health and the environment. Next, the addition of such material to the artifact should not require additional work for the craftsman in the workshop. Furthermore, the method used to extract peculiarity information should not adversely affect the artifact. Based on the above considerations, the following four requirements are established for artifact-metrics.

- Requirement 1: The risk of affecting the colors generated by the clay, glass, glaze, and paint of a material added to the artifact must be low.
- Requirement 2: The risk of affecting human health and the environment by the material must be low.
- Requirement 3: The addition of the material to the artifact must not require additional work by the craftsman in the workshop.
- Requirement 4: The peculiarity information can be extracted without contact with the product and in a short time.

C. Prerequisites

To define the scope of the discussion, the following prerequisites are established in this report.

- Condition 1: In this report, goods produced by the manufacturer every day are discussed. This means that goods already traded in the market or held by collectors (antiques etc.) are not included.
- Condition 2: In this report, the potential capability of the artifact-metrics proposed by the authors (capability to verify authenticity of the pottery, porcelain, and glass products) is discussed. Because the authors have not implemented the proposed method, detailed discussions of artifact-metrics (e.g., evaluation of capability of pattern matching devices or evaluation of clone resistance) are not provided.
- Condition 3: Counterfeit products mean products that are produced not using the manufacturer's genuine production process and bear false claims that they are made by such manufacturer (mimicking the design or engraving, etc.).
- Condition 4: Although the authors had not implemented the proposed artifact-metric system, discussions are based on the presumption that a reliable artifact-metrics system and trustworthy players (manufacturer, buyer, and retailer) are available.

III. Proposed Method

A. Material to Be Added in the Artifact

Glass phosphor [9] that is highly transparent and emits near infrared rays (peak wavelength of 1,000 nm) when irradiated by visible rays (optical excitation) drew the attention of the authors as the candidate material satisfying Requirements 1 and 2 above. Glass phosphor is produced by melting a mixture of powders consisting of small amounts of rare earth oxides and the supporting glass, which has the following characteristics.

1) As rare earth oxides that are relatively easily available are used and the weight ratio to the supporting glass is just a few percent, the production cost is low.
2) Because the main component is glass, the material is compatible with the glaze and paint as vitreous materials and with the glass products.
3) The risk of doing harm to human health (skin etc.) and the environment is low.

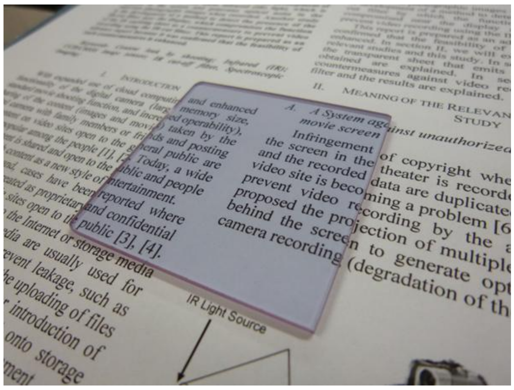

Fig. 2. Glass phosphor as a plate.

Color, transparency, and conversion efficiency from visible light to infrared rays of the glass phosphor are determined by the type and ratio of the rare earth oxides and the composition of the supporting glass. After examining the composition, the authors produced glass phosphor in which the color was reduced and transparency was improved (see Fig. 2). In Section IV, a description of the experiments by the authors is presented. While the glass phosphor the authors are seeking is completely colorless and transparent, the material has pale blue tint at present. While the authors continue to eliminate coloring because it is intended only to explain the concept and effectiveness of glass phosphor in this report, verification of the following points was aimed in the experiment.

1) *Difficulty in visual identification:* Only a small quantity of the glass phosphor will be added in the artifact considering the color of the glass phosphor, and it should be confirmed that a pale blue color is not easy to identify (i.e., addition of the glass phosphor cannot be known visually).
2) *Irradiation of infrared rays*: It should be confirmed that the glass phosphor added in 1) must irradiate low intensity infrared rays caused by optical excitation.

B. Production Process of Products and Method to Add Material

Fig. 3 and Fig. 4 show the fundamental production process for the pottery, porcelain, and glass products. The authors propose a method to add glass phosphor in the application of the glaze or paint in order to satisfy requirement 3. In this method, a security company produces and supplies glaze or paint that contains fine glass phosphor powder to the workshop. As no additional work is required, the glass phosphor can be added to the artifact during the usual work by the craftsman (i.e., application of glaze or paint).

Fig. 3. Fabrication process of pottery and porcelain products: material is added in application of glaze (dipping) or painting process.

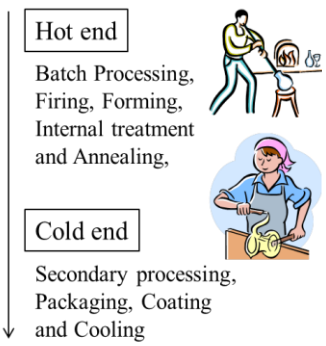

Fig. 4. Fabrication process of glass products: material is added in secondary processing where painting is involved.

Fig. 5. Fabrication process of pottery and porcelain products after bisque firing: the authors fabricated plates by the method shown in experiment 1.

Particles of the glass phosphor in the glaze or paint are deposited on the surface of the artifact with the components of the glaze or paint during the firing process, which comes after dipping and painting. During these processes, the position of the particles and the degree of bonding of the particles are incidentally and randomly determined and are different between individual products. Such information is used as the peculiarity information.

C. Extraction method of Peculiarity Information

The authors propose a method to photo-shoot the surface of the artifact illuminated by visible light (i.e., photo shooting irradiation of near infrared rays of the glass phosphor by optical excitation) to extract the peculiarity information that satisfies requirement 4. This is because the positions of the particles and the degree of bonding between particles correspond to the irradiating positions and the intensity of infrared rays due to the irradiation of visible light. When the information extracted as above is recorded in the reference data shown in Fig. 1, the judgment of authenticity of the products becomes possible.

The method proposed by the authors makes non-contacting and quick extraction of the peculiarity information possible, and the risk of adversely affecting the product is small because no ultraviolet rays, electromagnetic waves, or radioactive rays are used for extraction of the information.

IV. Experiments

The effectiveness of the proposed method and the glass phosphor at present can be confirmed when visual identification of the coloring due to the glass phosphor is difficult and irradiation of infrared rays by optical excitation is confirmed, when the experiment is conducted with a small quantity of the glass phosphor that has a pale blue color deposited on the artifact surface as explained in 3.1. The authors conducted two experiments to confirm the above two points.

Pottery products were used as the artifact on which the glass phosphor was deposited. Pottery was selected because temperature control in firing is easy using a simple electric furnace compared with porcelain or glass products.

A. Experiment 1

The experiment with respect to the first point (difficulty in visual identification) was conducted first. White unglazed plates were used so that the blue color could be easily identified, and 5 plates with glass phosphor deposition and 5 plates without deposition for a total of 10 plates were produced. Although the author proposed the addition of the glass phosphor by dipping or painting, the following procedures 1) and 2) were used for convenience in order to investigate the appropriate proportion of the glass phosphor in the glaze and paint and to verify that very small amounts of the glass phosphor have the same effect.

1) Unglazed plates were dipped in the glaze that becomes clear after firing, taken out, and dried [10].
2) Five plates were randomly selected from the 10 dried plates on which the surface mixture of the glass phosphor powder and ethanol was applied and dried. Portions where glass phosphor was applied were smoothed with a fingertip to spread out the glass phosphor particles to reduce the thickness of the glass phosphor layer. (See Fig. 6(a))

3) Plates were placed in the furnace. After the temperature was increased to 1230 degrees C for 8 hours, the furnace was left to cool naturally to room temperature. Then, the plates were taken out of the furnace and an identification mark was applied to the back of five plates to indicate the application of the glass phosphor.

Fig. 6(b) shows the different appearance as a result of spreading out the glass phosphor particles and Fig. 7 shows the plates with and without the deposited glass phosphor.

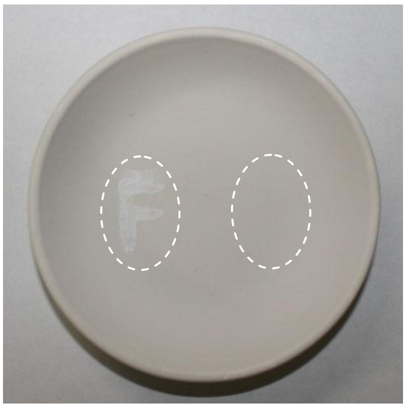

Fig. 6(a). Enclosed in the dashed line on the left: The glass phosphor is not spread out. Because the thickness of the glass phosphor layer is large, the area is identifiable. Enclosed in the dashed line on the right: The glass phosphor is spread out. Because the thickness of the glass phosphor layer is small, the area is not identifiable.

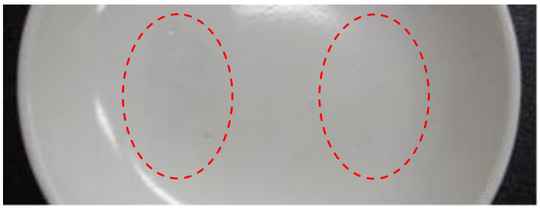

Fig. 6(b). Enclosed in the dashed line on the left: The glass phosphor is not spread out. Because the thickness of the glass phosphor layer is large, the area is colored blue. Enclosed in the dashed line on the right: The glass phosphor is spread out. Because the thickness of the glass phosphor layer is small, the blue color is difficult to identify.

Fig. 7. Left: Plate with deposition of glass phosphor (Glass phosphor is deposited in the area enclosed by the dashed line.) Right: Plate without deposition of glass phosphor.

Next, the following tests were conducted for 10 subjects after explaining the purpose of the experiment and the characteristics of the glass phosphor and the transparent glaze.

1) The experimenter selected 5 plates randomly from 10 plates outside the vision of the subjects.
2) After the subjects looked at the selected plates for 15 seconds, the subject was asked to answer whether each plate was deposited with the glass phosphor or not to the experimenter. The subjects were not allowed to examine the plates by hand.
3) After the subject answered the question, the experimenter looked at the back of the plate to see whether the glass phosphor was deposited, and 10 points were awarded for each correct answer. The subjects were not notified whether their answers were correct.
4) The experimenter repeated steps 1) and 3) 10 times to calculate the ratio of correct answers for the respective subjects.

TABLE I: TEST RESULTS

Subject	Points Obtained	Correct Answer Rate
A	170 / 500	34%
B	140 / 500	28%
C	240 / 500	48%
D	230 / 500	46%
E	170 / 500	34%
F	240 / 500	48%
G	180 / 500	36%
H	200 / 500	40%
I	190 / 500	38%
J	210 / 500	42%

Table I shows the test results. No subjects attained a correct answer rate exceeding 50%. This indicates that the glass phosphor is potentially effective and the identification of the color pale blue is difficult provided that it is deposited in small quantities (identification of the addition of the glass phosphor is visually difficult).

B. *Experiment 2*

Next, the experiment for the latter (irradiation of infrared rays by optical excitation) was conducted. Infrared spectral images were taken with a camera by irradiating visible light (laser beam: 808 nm) on two types of the plates prepared in experiment 1 according to the procedure shown in Fig. 8. The camera with an InGaAs image sensor sensitive to near infrared rays was used, and the optical filter that selectively passes infrared rays (IR85, RG830) was attached in front of the camera lens.

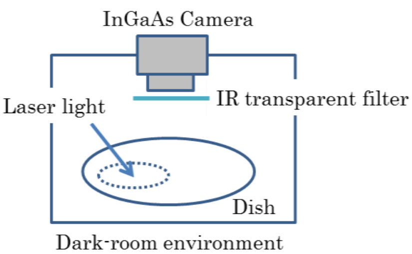

Fig. 8. Observation of Irradiation of IR rays.

The intensity of infrared rays is recorded as the intensity of brightness in the spectral image. Fig. 9 shows the infrared spectral image of the plates in Fig. 7. Irradiation of infrared rays was visible from the plate on which the glass phosphor was deposited but none from the plate without deposited glass phosphor. Also as shown in Fig. 10, spectral images of the plates with deposited glass phosphor are different, respectively.

From the above, it was confirmed that the glass phosphor continues to irradiate infrared rays due to optical excitation after firing, even in small quantities, and the infrared spectral image can be used as the peculiarity information.

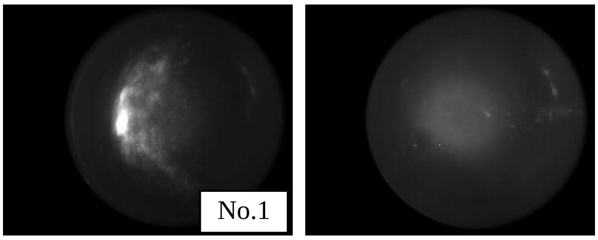

Fig. 9. Spectral Image. Left: Plate with deposited glass phosphor (No. 1); Right: Plate without deposited glass phosphor.

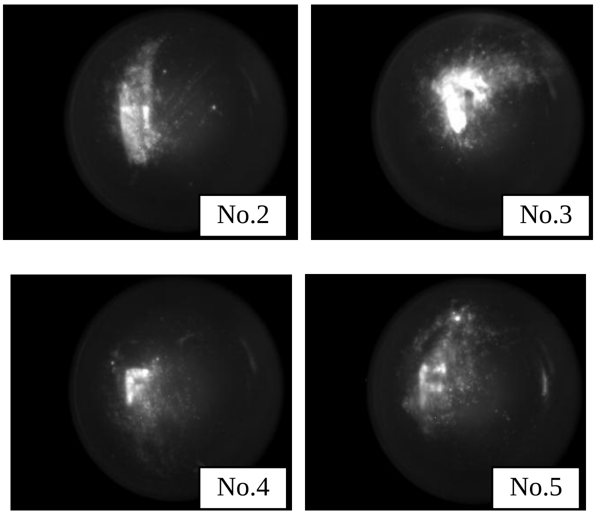

Fig. 10. Spectral Images of the plates (Nos. 2–5) with deposited glass phosphor.

V. Discussion

In this section, the discussion is to what extent the requirements are satisfied under the proposed method, and the counterfeiting prevention technology is evaluated.

A. Satisfaction of the Requirements

1) Requirement 1

As shown in Fig. 2, the glass phosphor has a pale blue tint at present. So when the glass phosphor is applied as a thick layer on the artifact, it is considered that the risk of affecting the colors generated by clay, glass, glaze, or paint is high. On the other hand, when a very small amount of glass phosphor is applied to the artifact, the presence of the glass phosphor is visually difficult to identify as the results of experiment 1 indicate, and it may be considered that the risk of affecting the colors generated by clay, glass, glaze, or paint is small.

Considering the above, the proposed method at this stage satisfies the requirement, although certain conditions apply (reduction of amount of glass phosphor attached on the artifact).

2) Requirement 2

While small amounts of rare earth elements (neodymium, ytterbium, samarium, praseodymium, etc.) are used to produce the glass phosphor, the expert opinion is that no apparent toxicity can be observed from the rare earth elements [11]. Materials of the supporting glass (oxide glasses of boron oxide system, phosphoric acid system, and boron anhydrate system) are stable oxides that are incombustible and insoluble, and it is said toxicity is very low. For example, lead oxide is contained in high quality transparent glass called crystal glass, and such glass is used as tableware, which indicates that the safety of such glass is high. Furthermore, glass phosphor, which is the compound between rare earth elements and the supporting glass, is a stable oxide glass that is incombustible and insoluble. As explained above, glass phosphor added to the artifact is less risky in affecting human health and the environment and satisfies the requirement. However, in handling glass phosphor powder, care should be taken to prevent inhalation and adhesion of the particles to the eye.

3) Requirement 3

The authors propose that a security company produces the glaze and paint containing fine glass phosphor powder and supplies them to the workshop of the artifacts. The production process will not be required to change because the glass phosphor can be applied to the artifacts via the ordinary work of the craftsman (application of the glaze or painting). This means that the proposed method will satisfy the requirement.

In certain workshops, preparation of the glaze and paint is made by the craftsman. In such a case, a new work step to add the proper amount of glass phosphor has to be included in the production process.

4) Requirement 4

As explained in Section IV-B, the infrared spectral image representing peculiarity information of the product can be obtained without contact with the product in a short exposure time (fast shutter speed). This means the proposed method satisfies the requirement.

In order to obtain the peculiarity information of the products quickly and effectively, it is necessary to know where the glass phosphor is deposited on the product.

B. Evaluation of the Proposed Method

For the evaluation of the counterfeiting prevention technology, it is at least necessary to consider security, convenience, cost, and social acceptance [12]. While the authors determined the potential effectiveness of the proposed method in Section IV, the system is not implemented yet. Accordingly, the authors evaluated each element based on the results of experiments and carried out a study towards system implementation.

1) Security

a) Evaluation of the proposed method:

As it is considered almost impossible to manipulate positions and the bonding of glass phosphor particles deposited on the artifact in the furnace, it is difficult to produce counterfeit products even if a malicious person were to obtain the genuine product to copy it.

b) Study towards system implementation

As far as the security of the artifact-metrics system shown in Fig. 1 is ensured, a malicious person cannot register the data for counterfeit products in the Reference Data, and thus distribution of the counterfeit product as a genuine product becomes impossible. In this artifact-metrics system, certain variations exist between the respective optical systems to obtain peculiarity information (infrared spectral images), and because environmental conditions (e.g., positions where the product and the camera are placed, lighting condition, etc.) vary between the systems, the peculiarity information registered in the reference data and the peculiarity information obtained for verification of the product will not completely match. In the system to be implemented, certain thresholds must be incorporated to allow such variations, but this may also determine a counterfeit product as the genuine product subjected to a brute force attack [12], wolf attack [12], and hard copy attack [12]. So, the system is required to establish the thresholds considering such possible attacks.

2) Convenience

In this section, the ease of adding a material to the artifact and the ease of detecting peculiarity information are discussed.

a) Evaluation of the proposed method

With respect to the ease of adding a material, because no additional work process is required as explained in 5.1.3, we can say material addition is easy. With respect to detection of peculiarity information, it can be obtained simply and easily by photo shooting the products with an exciter light as explained in 5.1.4, and we can say detection of the peculiarity information is easy.

b) Discussions towards system implementation

With respect to the ease of adding the material, smoothness must be increased by making the glass phosphor into a fine powder so that a craftsman will not feel differently when applying glaze or paint. With respect to the ease of detecting peculiarity information, information on the position where material is deposited must be easily available to the verifier as explained in 5.1.4. For example, an instruction manual indicating such position should be attached to the products and posted on the manufacturer's website.

3) Cost

The cost of the glass phosphor per one piece of the product is discussed here.

a) Evaluation of the proposed method

While a thin layer of glass phosphor was created by smoothing out the material with a fingertip as shown in Fig. 6, the thickness of the layer is not measured. Accordingly, it is assumed that the glass phosphor is spread over an area 20 mm square and the thickness of the layer is about the diameter of hair (0.08 mm). As the mass of the glass phosphor shown in Fig. 1 (50 mm square and thickness of 3 mm) is 22 g, the mass of the glass phosphor layer (20 mm square and thickness of 0.08 mm) becomes 0.094 g (using this number, appropriate mixture of glass phosphor in the glaze or paint can be obtained). The glass phosphor block in Fig. 1 was cut from 1 kg of glass phosphor. To make 1 kg of glass phosphor 3,344.95 USD was required, which means that 0.094 g of glass phosphor costs 0.31 USD. This value is less than the average price of an RFID tag of the same size (0.8–1.20 USD). Affixing the RFID tag may impair the design of the product, but deposition of the glass phosphor will not, because identification of the glass phosphor is difficult. As discussed above, we can say the glass phosphor is a cost effective security material.

b) Discussions towards system implementation

The above values are the charge when 1 kg of the glass phosphor is produced on a trial basis. The points are that easily available rare earth oxides are used to produce the glass phosphor and they occupy only a few weight percent of the supporting glass (a few grams per 100 g of the supporting glass). In practical application, a large amount of glass phosphor will be produced, and it will be possible to obtain glass phosphor for less than the value explained above.

4) Social acceptability

The safety of the glass phosphor and the feasibility of expanded use of the proposed method (acceptability of the method) are discussed here. Safety was already discussed in 5.1.2 and therefore the discussion is not repeated.

a) Evaluation of the proposed method

While experience and special expertise and skills are required for verification of the authenticity of valuable pottery, porcelain, or glass products, the proposed method, when used, may allow a person without such expertise and skills to determine the authenticity of such products. Because of the above, the proposed method is likely to be employed in the business of valuable pottery, porcelain, and glass products not only by parties upstream of the business (authorized distributor, trading firm, etc.) but also by parties downstream (second-hand goods traders, consumers, etc.), and we can say that the proposed method is easily accepted by society.

b) Discussions towards system implementation

So that the proposed method is widely accepted by society, the authors consider that development of an inexpensive and accurate artifact-metrics system and the development of inexpensive tools that can easily determine authenticity are required, like in the case of the verification method for bank notes or securities. At this moment, construction of the artifact-metrics system requires a large investment, and no method that can be easily used for verification of authenticity is available, and the authors consider measures and methods that solve such issues are required for implementation of the system.

VI. Conclusion

The authors proposed artifact-metrics that make verification of authenticity of valuable pottery, porcelain, and glass products possible and make production of counterfeit products difficult. The method satisfies the four requirements defined beforehand. The concept of the authors and the effectiveness of the glass phosphor at this stage were confirmed by basic experiments.

The glass phosphor aimed by the authors should be completely transparent and colorless, but it is pale blue tinted at this stage. The authors intend to examine the composition of the glass phosphor to eliminate any color tint to obtain a completely transparent and colorless material.

Pottery products were used in the experiment because temperature control in firing is easy, and the intention is to conduct similar experiments for porcelain and glass products to verify the effectiveness of the concept and the glass phosphor.

The authors intend to promote and expand the use of the proposed method while investigating the need for the method through interviews with manufacturers and potters and to resolve the issues discussed towards implementation.

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