EP2-3L
Late-News Paper
Invited

Invisible Digital Image by Thin-film Interference of Nb_2O_5 using its Periodic Repeatability

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Keywords: Invisible Digital Image, Thin-film Interference, Periodic Repeatability

ABSTRACT

We have succeeded in making an invisible digital image on a metal substrate using periodic repeatability by thin-film interference of niobium oxides. Although this digital information is invisible in the visible light range, but detectable in the infrared light range. This technology has a potential to be applied to anti-counterfeiting and traceability.

1 Introduction

What is the significance of information that is invisible to the human eye? The invisibility here assumes that the information can be visualized and quantified by instruments. In fact, the advantages of such invisibility are so many. For example, invisible digital information embedded on the surface of a product gives anti-counterfeiting effects without damaging the appearance of the product. There is a potential need for QR Codes® and barcodes to be invisible on the surface of packaging especially for luxury brand products. Moreover, since these barcodes are invisible, they can be embedded anywhere on the package. This would allow self-checkout machines to read barcodes without having to check their position.

On the other hand, we have been studying the mechanism of coloration by thin film interference [1] using a thin film of niobium oxide (Nb_2O_5) on a metallic niobium plate. In the process, we have observed that similar colors are periodically repeated depending on the thickness of the oxide film. For example, when the thickness of niobium oxide is around 100 nm, nearly achromatic color is observed, as in the original niobium substrate as shown in Fig.1. This is presumably because the wavelengths that are strengthened and weakened by thin-film interference are outside the visible light range.

In this present work, we applied this periodic repeatability to invisible digital information. If a 100 nm niobium oxide film could be formed at an arbitrary position on a niobium substrate, it would be possible to form an image that is invisible in visible light but detectable in infrared light. For example, it would be possible to form a QR code that is invisible with visible light but detectable with an infrared camera.

2 Invisible Digital Image

2.1 Formation of Invisible QR Code®

The key to achieve an invisible image is how close the color of the niobium oxide thin film on the niobium substrate can be made to the color of the niobium substrate (achromatic color) in the visible light region. The specific method is described below.

The toner was transferred onto a PET film by a laser printer (LP-7010C, Canon), and a mask for QR Code® was fabricated. A positive photoresist solution was spin-coated on a niobium plate (30 × 40 × 0.1 mm) and dried in a dry oven. Next, the above mask containing the QR Code® information was exposed to ultraviolet light while overlapped on the niobium plate and developed. The anode was then oxidized according to the conditions required to form a 100 nm niobium oxide layer. In other words, anodic oxidation was performed using a photo masked niobium plate as the anode and a platinum-coated titanium electrode as the cathode at an applied voltage of 40 V in citric acid solution for 60 sec.

Nb_2O_5 thickness (nm)	0	25	50	75	100	125	150	175	200	225	250
Coloration by thin film interference											

Fig. 1 Color images which exhibit periodic repeatability by thin film interference as a function of the thickness of Nb_2O_5

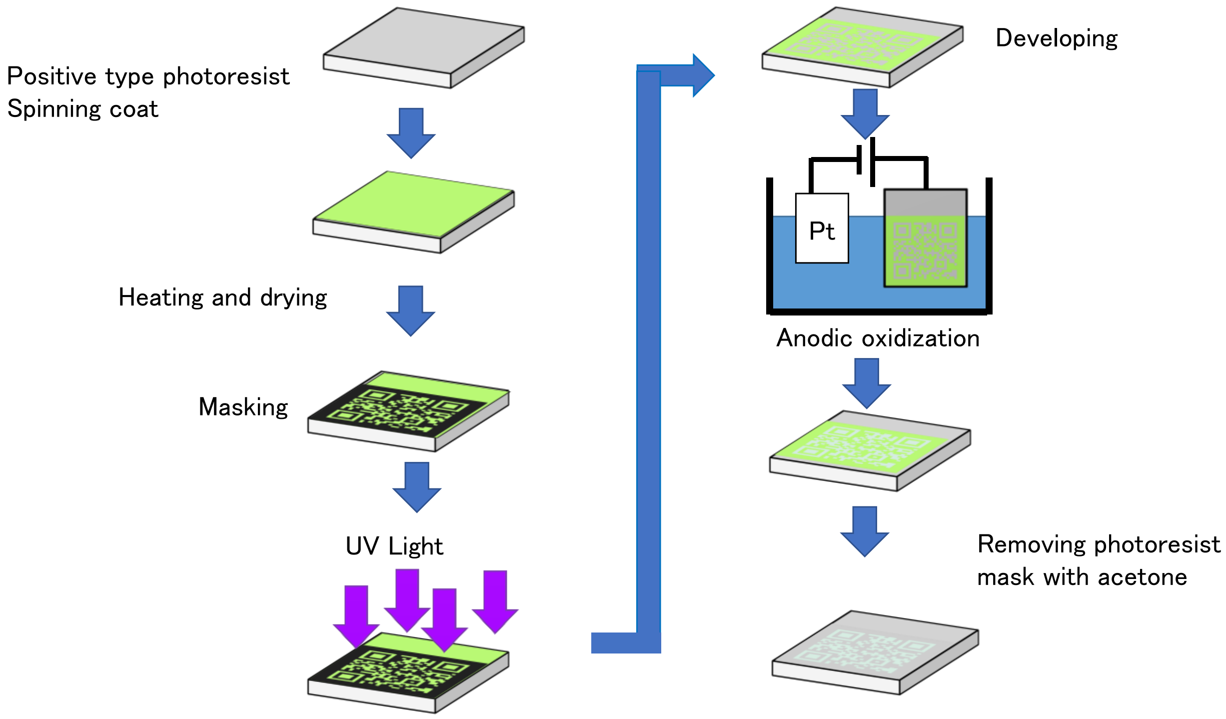

Fig. 2 Fabrication of masks for QR code® and anodizing of niobium

Finally, the resin remaining on the substrate was washed off with acetone. The process up to this point is summarized in Fig. 2. The portion to be left as the substrate was masked with resin using the photomask-photoresist technique, and only the portion where the QR Code® will be printed was anodized.

2.2 Evaluation of Invisible QR Code®

A niobium plate with a QR Code® was photographed with a visible light camera (iPhone 11, Apple) and an infrared monochrome camera with a 940 nm LED (MK-0323, Mintron Enterprise) under an indoor light source. The captured images were displayed on an LCD display (DELL S2240L), and QR Code® was read using a code reader (iPhone 11, Apple).

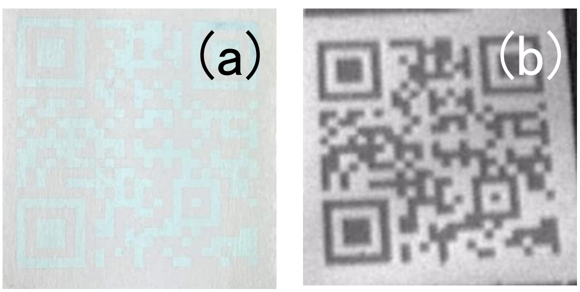

Fig. 3 QR Code undetectable under visible light (a), detectable under infrared light (b)

The niobium plate embedded with QR Code® made by the above process was hardly visible under visible light, and the contrast was very small (Fig. 3(a)). No digital information was read from the QR Code®. On the other hand, the QR Code® obtained from the infrared camera had sufficient contrast to be detectable, as shown in Fig. 3(b), and it was possible to jump to an actual homepage.

3 Conclusions

We have introduced digital information that is invisible in the visible light range and detectable in the ultraviolet/infrared light range using periodic repeatability by thin-film interference of niobium oxides.

This paper focused on only achromatic colors (achromatic QR Code®/achromatic background), but we have already found combinations in which both the QR Code® and the background are magenta, yellow, cyan, etc. in the visible light range and contrast is produced in the infrared or ultraviolet range. Invisible QR Code® using can be expected to be applied to anti-counterfeiting, traceability, and other fields.

References

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