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DESIGN OF A THIN FILM INFRARED BARCODE ON A FLEXIBLE SUBSTRATE

Brian Monacelli,[1] Dale Kotter,[2] and Glenn D. Boreman[1]

[1]*School of Optics—CREOL & FPCE*
University of Central Florida
4000 Central Florida Boulevard
Orlando, Florida 32816-2700, USA
[2]*Idaho National Engineering and Environmental Laboratories (INEEL)*
P.O. Box 4000,
Idaho Falls, Idaho, 83415, USA

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Abstract

We report the design, fabrication and characterization of an infrared barcode. This barcode is composed of a bilayer of titanium and amorphous silicon on a flexible Kapton substrate. Information encoded in the barcode shows high contrast when viewed with an infrared imaging system in the 8 to 12μm spectral region. The barcode information is concealed under visible viewing conditions, i.e., the barcode appears as an untreated, uniform metal sheet to a detector of visible radiation (400 to 700nm).

Keywords: infrared thin film barcode; infrared information encoding

1. Introduction

We use the fact that the optical thickness of a film scales with the illumination wavelength to create a unique device. A barcode is composed of film layers that act as a bulk medium to visible radiation, but appear as a thin film device in the infrared. Thus, information can be encoded with excellent contrast when viewed with an infrared imaging system in the 8 to 12μm spectral region, yet it will be concealed under standard viewing conditions. That is, the barcode has a uniform appearance and shows no contrast between characters of the encoded information when viewed with a visible imaging system. The barcode is composed of multiple layers on a flexible substrate. Kapton is used as the substrate and titanium and silicon are the deposited layers. The silicon layer defines the barcode information by contrasting high reflection (HR) or antireflection (AR) silicon film thicknesses in the mid-infrared spectral region. Both silicon thicknesses appear as a bulk film to visible radiation and will therefore show no visible contrast.

2. Fabrication

The barcode is composed using Kapton as the flexible substrate. The Kapton is commercially available as a 127μm thick polymide; it is made by Dupont. It is commonly used as a substrate in the fabrication of microelectronic circuits and devices when it is desirable to form a circuit to its packaging. Kapton is also used because it is a good absorber of infrared radiation. This is a useful characteristic for the barcode substrate because increased absorption of thermal (infrared) radiation can lead to higher contrast of the barcode information.

To prepare the substrate, it is thoroughly cleaned with isopropyl alcohol. Two thin film layers are then vacuum deposited in a MRC 8667 sputtering system. The initial layer is a 50nm thick layer of titanium that is applied via dc magnetron sputtering in an argon ion atmosphere at a pressure of 3mtorr. The dc power used to form the argon ion sputtering plasma is 2kW. This layer acts as the primary absorber of infrared and visible radiation, thereby nullifying broadband radiation transmission through the barcode.

The top layer is composed of amorphous silicon, which is applied via rf diode sputtering at 1kW in an argon ion atmosphere at a pressure of 4mtorr. This layer contains the barcode information – the silicon layer is either a high reflection (HR) coating (in the region containing the characters of the barcode) information or an antireflection (AR) coating (in the region surrounding the barcode characters). The HR coating is a thick layer of silicon that acts as a half-wave film in the 8 to 12μm region of the infrared; the AR coating acts as a quarter-wave film in this spectral region. During processing, these different silicon layer thicknesses are distinguished by inserting a stencil template over the barcode, thereby encoding the information. This template is composed of brass, so that it is both thin and heavy. A thin mask is desirable so that the boundary between the AR and HR coatings is abrupt but without feature. A heavy mask is used to assist in maintaining substrate flatness during deposition.

3. Design and Characterization

These materials are chosen based on the practical reasons mentioned in section 2 and because of their availability and their ease of use in a thin film deposition process. The design parameters of interest are the film thicknesses and the composite barcode reflection and absorption. Since the composite barcode transmission is designed to be negligible, the barcode reflection equals one minus the barcode absorption at any particular wavelength.

The film thicknesses are optimized using The Essential Macleod thin film design software [1]. A design was composed to optimize the film reflection from 8 to 12μm by varying the amorphous silicon thickness. The AR coating of silicon was optimized to be 624nm thick and the HR coating was optimized to be 1235nm thick; these film thicknesses correspond to quarter-wave and half-wave films at 10μm. The simulated design of the infrared signature is plotted in Figure 1 from 8 to 12μm. The maximum absorption of the AR layer is >95%. The minimum absorption of the HR layer is <19%. The transmission is assumed to be nearly zero throughout the spectrum because of the inclusion of the titanium layer and the use of the Kapton substrate.

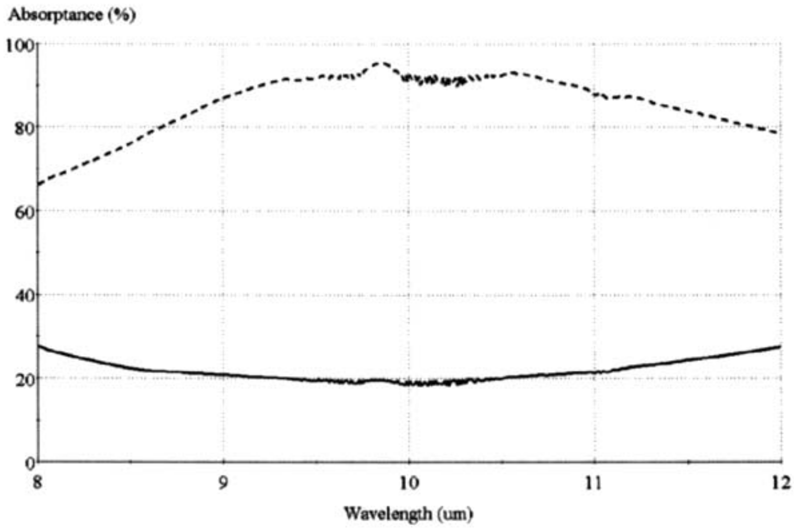

Figure 1. Infrared absorption by the thin film barcodes. This shows the high contrast in absorption in the infrared spectral region from 8 to 12μm. The high reflection (HR) coating is the solid line and the anti-reflection (AR) coating is the dashed line.

The barcodes also feature a uniform visible signature. Though the two silicon layer thicknesses show excellent contrast in the 8 to 12μm region, they must show no difference in reflection from 400 to 700nm. The visible performance of the barcodes is shown in Figure 2. The reflection of the barcode is nominally 60% throughout the visible, causing the barcode to appear as an unpatterned, uniform partial mirror. To mitigate the specular reflection from the film, the barcode was subjected to a glass bead blasting. This process roughened the surface and made the reflection more diffuse, but did not alter the overall spectral signature.

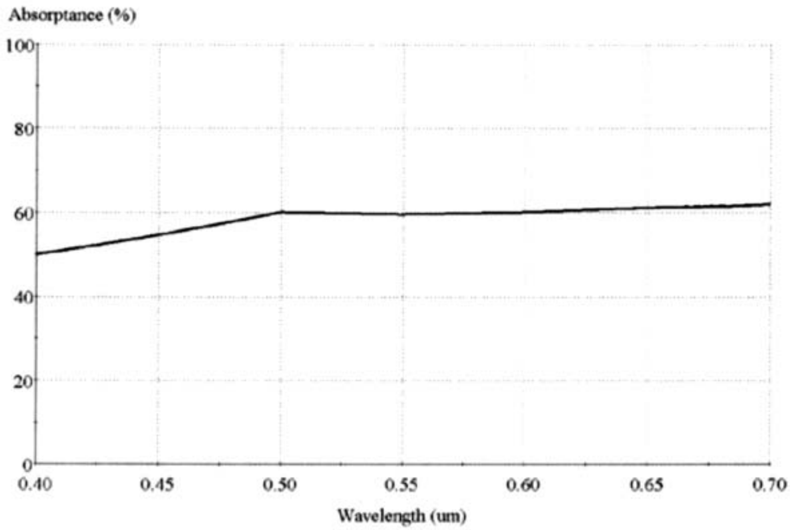

Figure 2. Visible absorption by the thin film barcodes. This shows the barcodes' visible signature. HR and AR performances are indistinguishable from 400 to 700nm. The barcodes appear as a partial mirror in this spectral region.

4. Application

Figure 3 shows the barcode when viewed with a Raytheon ControlIR 2000B infrared camera that has a spectral window from 8 to 12μm. Figure 4 shows a photograph of the barcode, taken with a Nikon D1X digital camera. The Kapton substrate is evident in the barcode periphery of the visible image. Protruding substrate (remaining from processing) can be easily cut away for application. Thus, this device can be fabricated to any dimension. The main limitation of barcode resolution is the size of the information encoded in the template.

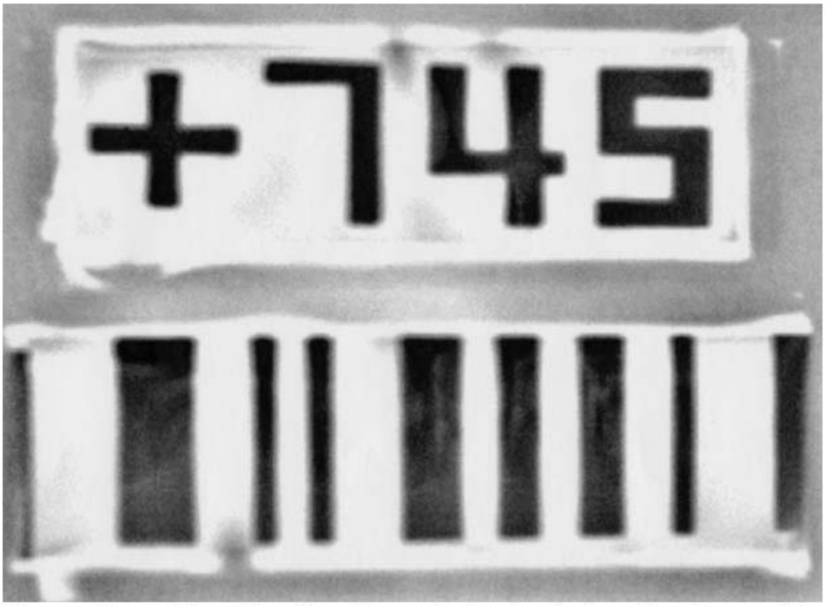

Figure 3. The thin film barcode in the infrared, taken with a Raytheon ControlIR 2000B camera, equipped with optics that view from 8 to 12μm.

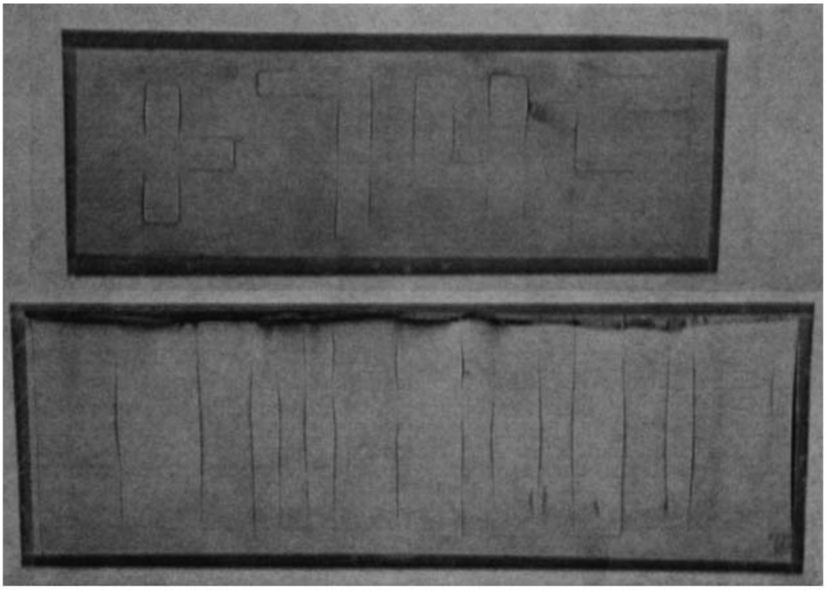

Figure 4. The thin film barcodes in the visible, taken with a Nikon D1X digital camera. The edge effects are evident because the template shadowed the substrate and graded the silicon deposition.

A slight indication of the barcode information is available in the visible; this is barely evident in Figure 4. The thin lines surrounding the edges of the information are due to the fact that the barcode template partially shadowed some regions of the substrate during the silicon deposition, causing a localized graded silicon deposition. These blemishes can be reduced by reducing the thickness of the barcode template or by depositing the top silicon layer via a more directional physical vapor deposition technique, such as evaporation.

A potential application of these barcode devices is to apply the barcode on arbitrarily-shaped equipment, as shown in Figures 5 and 6. The barcodes are applied to a car and are imaged with an infrared and visible camera. Only in the infrared image is the high contrast barcode information evident. The flexible substrate infrared and visible camera. Only in the infrared image is the high contrast barcode information evident. The flexible substrate allows the barcodes to be contoured to the car's body and the metallic visible appearance of the barcodes helps them blend with the car's metallic color. Ambient radiation (e.g., from the sun) increases the infrared barcode signature by heating the barcode – more absorbed radiation yields a brighter appearance of the AR silicon layer, but does not brighten the HR layer. Thus, the barcode contrast is enhanced. The visible signature remains unaffected by ambient conditions.

Figure 5. An application of the thin film barcodes. The infrared image is taken with radiation from 8 to 12μm. This automobile was allowed to sit in the sun and barcode contrast was enhanced.

Figure 6. The visible image of the barcode application. The barcode forms to the contours of the automobile's door and blends with its metallic color.

5. Conclusion

A device has been designed that encodes information by employing thin film effects in the infrared spectral region. To visible radiation, these films have bulk metal properties such that the encoded information cannot be gleaned by visible inspection.

Acknowledgments

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