euspen's 25th International Conference & Exhibition, Zaragoza, ES, June 2025
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Thermal transmission imaging of an opaque thin layer structure

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Abstract
This study investigates the transmissive thermal inspection of opaque, thin and flat objects illuminated from the back. The target objects were composed of thin multi-layers that were not transparent to visible wavelengths and had different thermal conductivities. The thermal source for thermal transmission imaging (TTI) generated long-wave infrared (LWIR) rays, which have higher transmittance and penetration through the thin layer structure. Because of the LWIR characteristics, TTI is advantageous for detecting the internal discontinuities of thin layer structures, such as cracks, corrosion, voids, and impurities. The thermal distribution on the non-defective surface was uniform, but thermal leakage and barriers occurred caused in the defective area. Therefore, TTI can assist in visualizing these leakages and barriers in a thin layer using back-side illumination. In the experiments, defects in flat panel displays and oil paintings were observed using a thermal camera, halogen lamps, and a germanium filter. TTI detected internal defects in the thin layer architecture from thermal images acquired on the front side. The proposed method can be applied to inspect flat panel displays and to investigate art work.

Thermal conductivity, defect, image, inspection

1. Introduction

Thermal imaging is a non-contact and non-destructive inspection method for acquiring long wave infrared (LWIR) images of a target object. Thermal imaging shows the temperature distribution of a target object and is widely used in science, industry, security and safety. Thermally reflective and emissive image are the conventional approach because they intuitively represent the thermal status of a target object.

The material properties of thin film structures have been measured using conventional thermal imaging. The in-plane thermal conductivities of InAlGaAs and Si films can be accurately measured using thermo-reflectance and heat diffusion imaging, respectively [1,2]. In these thermal images, the target object was heated using a thermal source that was placed on the same side as the target object and the thermal camera. Thermal diffusivity imaging was proposed to measure the diffusivities of Cu and Al [3]. A metal sheet was placed between the heat source and the thermal camera, and the thermal diffusivity was obtained from thermal images after heating the metal sheet. The LWIR emissivity of a glass panel for a solar photovoltaic plant was measured using a bolometric thermal camera [4].

Although thermal reflective and emissive imaging techniques are popular, the thermal transmission imaging (TTI) of thin films has rarely been discussed. Gracias devised a TTI system to inspect the voids in bonded Si wafers [5]. A circular cavity was detected using TTI and verified using photoacoustic imaging. Tonkin experimented with optical materials for LWIR transparency, but the study focused on the material properties of the optical components of LWIR imaging rather than TTI [6]. LWIR can permeate and penetrate opaque materials for visible rays; thus, TTI has great potential for inspecting inner defects hidden beneath an object's surface and in thin objects. In this study, an inspection method for finding inner defects in an opaque thin layer structure (OTLS) is proposed using the LWIR penetration and transmission characteristics. TTI was used experimentally to visualize the inner defects of flat panel displays and oil paintings.

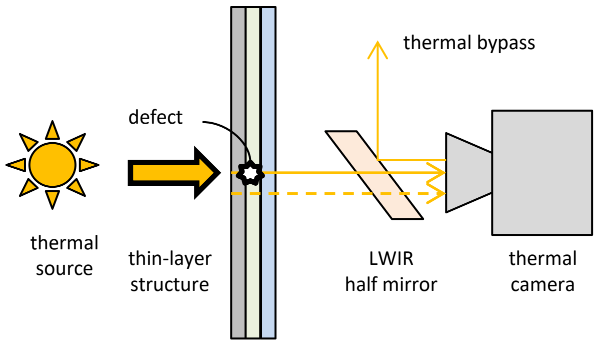

Figure 1. Conceptual diagram of thermal transmission imaging

2. Materials and methods

2.1. Principles

The TTI concept in this study is presented in Figure 1. The thermal source, OTLS, half mirror and thermal camera were sequentially placed along the horizontal axis. The thermal source radiates the LWIR into the OTLS, and part of the LWIR reaches the thermal camera. Each layer of the OTLS was uniform and thin; however, their thermal conductivities were different. When a layer of the OTLS was not transparent to the LWIR, the LWIR changes into thermal energy, and the temperature of the layer increases. Subsequently, thermal energy was transferred gradually from the source side to the camera side of the OTLS. A crack and void in the OTLS leaked the LWIR; thus, the defective area becomes bright, and the non-defective area was dark in the thermal image. On the other hand, the defective area becomes dark and the non-defective area becomes bright when defects such as impurities obstruct the LWIR. These defects break the uniformity of the LWIR transmission in 2D space; thus, the defects are visualized with different intensities by the thermal camera. An LWIR half-mirror is necessary for this concept because LWIR is also generated by the thermal camera. The LWIR from the thermal camera is reflected from the OTLS and sensed by the thermal camera, and should therefore be removed. In this study, a half-mirror was installed to ensure that the LWIR bypassed the thermal camera, which prevented the LWIR from regularly reflecting on the OTLS surface.

2.2. Experiment

The experimental apparatus was constructed using a thermal camera (Optris PI640), halogen lamp, and germanium filter. A halogen lamp (60 W) was used as the LWIR source because it generates high-power light with a broad range of wavelengths, including LWIR. The current driving to the halogen lamp was adjusted using a variable DC power supply to prevent overheating of the OTLS. The germanium filter was highly polished to obtain a reflective surface and used as the LWIR half-mirror [7]. The test samples were an AMOLED panel and oil paintings. The thermal images were acquired by focusing on the OTLS after the halogen lamps were activated. Figure 2 shows the experimental setup for the oil painting.

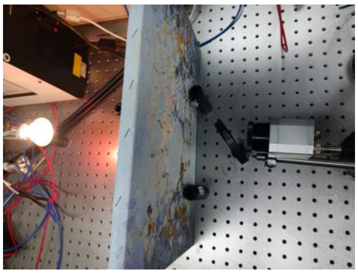

Figure 2. Experimental setup for the oil painting

3. Results and discussions

Cracks and impurities in the samples were detected using the TTI; however, the characteristics differed according to the materials in the samples. Figure 3 shows the color-map images acquired from a wafer and an AMOLED panel using TTI. The image of the wafer shows that the Si substrate is bright and the patterns are dark. The patterns are usually created by conductive materials such as Al, Cu, and Au. These metallic materials are not transparent to LWIR; thus, the patterns form dark shapes. The image of the AMOLED panel shows bright cracks and dark non-defective areas. The multi-layer panel was built with a thin steel plate, an AMOLED layer, films, and a glass cover. The thermal source heats the metal plate, which is opaque to LWIR. The heated metal plate induced LWIR, which passed through the cracks but was obstructed in the non-defective areas. Thus, the cracks appeared bright in the AMOLED image obtained using TTI.

The gray-scale images of the oil paintings in Figure 4 exhibit different characteristics. The LWIR was almost transparent to any color of oil paint. The black paint absorbed the visible rays but the LWIR permeated the black paint. Oil painting images using TTI conventionally show a cumulative form, and slight differences are observed according to the depth of the oil paints. Thus, the oil paintings in the visible region look different than the thermal images. However, dark patterns are observed in the thermal images where impurities are present. In the experiments, metal powder and a lump of dust were detected as dark patterns. Metal is usually opaque in LWIR; thus, metal on an oil painting forms a dark pattern in TTI.

The experimental results using a wafer and AMOLED panel show that cracks and metallic patterns can be observed using TTI, although a specific layer in the OTLS is opaque to the LWIR. The cracks are displayed as bright shapes and are clearly visible. Experimental results using oil paintings show that TTI exhibits high transparency in paints and can detect impurities.

The experimental setup for TTI is simple and inexpensive. Furthermore, TTI acquires images from the front of reflective objects, whereas conventional thermal imaging captures them by tilting the thermal camera. Therefore, TTI can be useful for inspecting semiconductors, flat panel displays and art works.

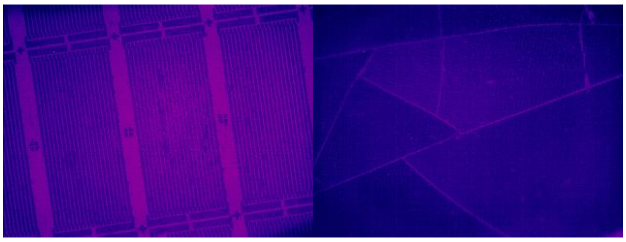

Figure 3. Patterns on a wafer (left) and cracks in the AMOLED panel (right)

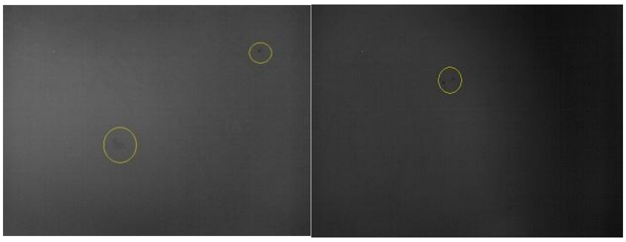

Figure 4. Impurities detected in oil paintings

4. Conclusion

TTI imaging was proposed for inspecting the inner defects of an OTLS using LWIR penetration. The TTI setup was constructed using a thermal source, an OTLS, an LWIR half-mirror, and a thermal camera. The TTI components were placed along an axis, and images were acquired in front of the OTLS. TTI detected cracks, voids, and impurities in the OTLS. TTI can be inexpensively established and is useful for inspecting the inner defects of an OTLS.

Acknowledgement

This research was supported by Culture, Sports and Tourism R&D Program through the KOCCA grant funded by the MCST (Development of AI-based art work data acquisition management and value analysis support technology, RS-2024-00439361, Contribution Rate 100%).

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