THz-ARTE: non-invasive terahertz diagnostics for art conservation

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***Abstract*— The project THz-ARTE "Terahertz Advanced Research TEchniques for non-invasive analysis in art conservation" has recently been selected in the area of Technologies applied to Cultural Heritage in the framework of the Agreement between the Government of Italy and the Government of Japan on cooperation in Science and Technology.**

I. Introduction and Background

THz imaging is a rapidly developing technique with many applications in a variety of fields from biomedicine to material science, from security to environmental studies. Recently the application of THz imaging to art conservation has been proposed [1]. When compared with other techniques currently applied to the characterization of materials used in art, like mid infrared spectroscopy and X-ray analysis, which are used to identify organic and inorganic materials respectively, Terahertz spectroscopy is expected to identify composites themselves and to give clear and direct information for art conservation.

The main objective of THz-ARTE is the demonstration of terahertz spectroscopy and reflective terahertz imaging as new non-destructive analysis tools of art objects, including paintings, murals, colored or varnished sculpture and colored furniture. The project is addressing in particular:

- The comparison of different spectroscopic techniques in various frequency ranges from the near IR to the microwave region and the setup of a THz database for art materials;
- The investigation of hidden, stratified and plaster covered paintings by reflective THz imaging techniques that may lead to the identification of original layers;
- Research on ageing mechanism of art materials and proposals on accelerated ageing test of new materials for conservation.

II. Results

Preliminary measurements on non-invasive diagnostics for multi-layered art objects have been conducted utilizing a reflective imaging set-up.

The 150 GHz radiation generated by the ENEA Compact-FEL [2] is coupled into a focusing cone followed by a circular to rectangular waveguide transition, which matches the cone output to a series of two WR6 directional couplers. A microprobe end is attached to the second directional coupler directing the 150 GHz radiation to the surface of the sample under investigation. The side outputs of the two directional couplers provide a reference signal of the FEL radiation incident on the sample and the signal reflected by the sample respectively. Both signals are detected by Schottky diodes at room temperature. The sample under investigation is placed on top of a XY translational stage driven by piezo-motors with 50 mm travel range on both axes (see Fig.1). Images of the sample can be acquired with a spatial resolution up to 0.2 mm [3]. Scanning the sample along the Z axis also provides phase information.

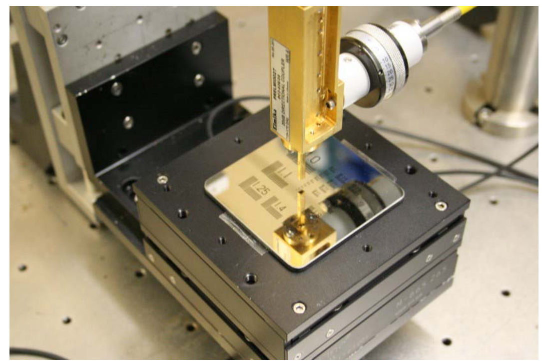

Fig.1 – THz reflective imaging set-up

Results on the detail of a painting covered by gesso are shown in Fig.2.

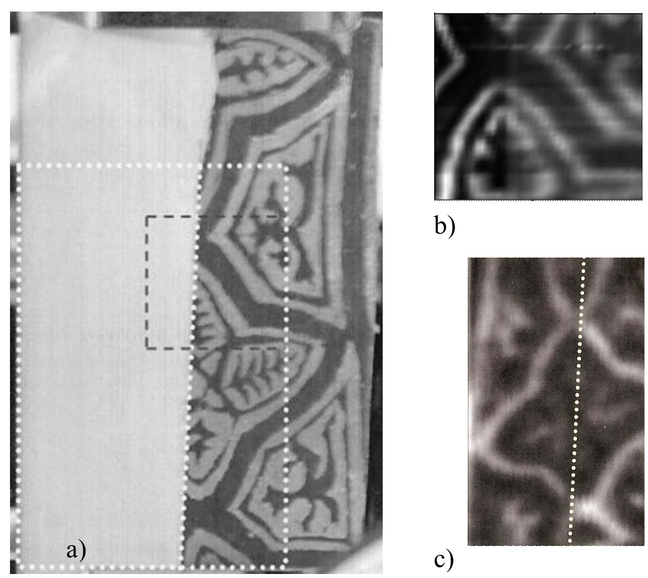

Fig.2 – a) visible image of a tempera painting partly covered by gesso; b) THz image in reflection @ 0.15 THz of the detail shown in the dashed square of the visible image; comparative image in transmission @ 0.6-2.6 THz of the detail shown in the dotted area of the visible image.

The THz image is taken about 1 mm above the surface of

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the painting. It clearly shows a better contrast in the area covered by gesso. An analysis of the effect of different thickness of gesso on the THz image is in progress. Another example is reported in Fig. 3, where the masking process with gesso of a detail of a oil painting is shown together with a terahertz image in reflection (represented in false colors). Also in this case the original image is clearly visible under the gesso layer.

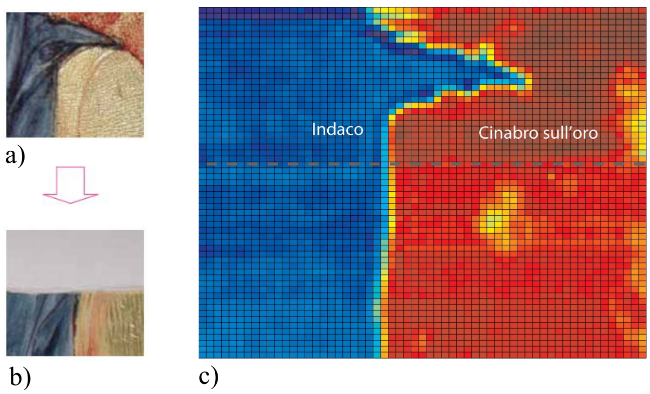

Fig.3 – a) detail of a oil painting; b) same detail partially covered with gesso; c) THz image of the detail covered with gesso.

The signal reflected from the samples interferes with the reflection from the open end of the waveguide, providing phase information, which can be used to enhance the image contrast and to monitor topological features of the sample surface.

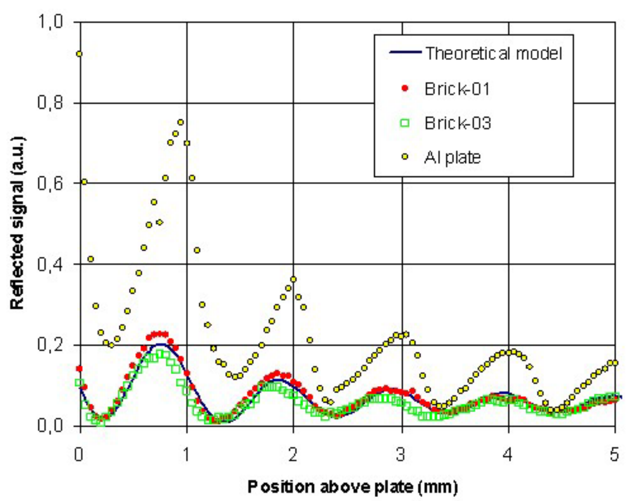

Fig. 4 – Measurement of the reflected signal as a function of the distance between the probe tip and the sample (see text for details).

The imaging system has also proven to be a valuable tool for the investigation of the dielectric properties of different materials. The complex index of refraction can be calculated from the fit of the z-profile of the reflected signal with a simple theoretical model based on the diffraction by a rectangular aperture. An example is given in Fig. 4, where the normalized reflected signal is plotted as a function of the distance of the waveguide tip from the sample for a solid brick and an aluminum reference plate respectively.

A number of common pigments have been measured in this way. The measured power reflection coeeficient and the derived values of the real and imaginary part of the comlex index of refraction as well as the power absorption coefficient are reported in Table I for different materials.

Table I

Material	Power reflection	Re(n)	Im(n)	α (cm-1)
COP plate	0.14	1.04	0.81	25.01
BCA Blue Cobalt Acrylic on COP	0.03	1.30	0.26	8.06
BCO Blue Cobalt Oil on COP	0.04	1.46	0.06	1.81
Oil	0.03	1.15	0.36	11.36
Wax	0.03	1.32	0.28	8.35
Balsam	0.03	1.42	0.11	3.10
Solid Brick	0.15	1.55	0.90	27.68

A reflective THz imaging scanner will be developed, capable of providing images of large sampling areas (typically 1x1 m^2 with a lateral resolution of about 0.5 mm) at frequencies in the range between 100 and 300 GHz.

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