New tools for advance in thermal nanometrology using scanning thermal micorscopy

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Fundamental research and continued miniaturization of materials, components and systems have raised the need for the development of thermal-investigation methods enabling ultra-local measurements of surface temperature and thermo-physical properties in many areas of science and applicative fields. Scanning Thermal Microscopy (SThM) is a promising SPM based technique for sub-micrometer-scale thermophysical measurements, thermal imaging and study of thermal transport phenomena within materials as well as between objects that are in near-field interaction. In many cases, the link between the nominal signal measured by a thermo-resistive SPM probe, which is operated as ultra-localized thermal source and/or thermometry sensor, and the investigated parameter is however not straightforward due to the complexity of the micro/nanoscale interaction between the probe and the sample. How to better manage this interaction? When SThM experiments are performed under ambient air conditions the interpretation of the measurement requires the the description of the various heat transfer mechanisms involved between the probe, i.e. the cantilever and the tip, and the sample. These mechanisms include thermal radiation and heat conduction through the air, the water meniscus and mechanical nanocontacts when tip and sample are in contact. Although they have been studied for more than 20 years for SThM, they are still not completely understood [1]. SThM experiments under vacuum conditions can allow the investigation of thermal conduction at solid-solid mechanical nanocontacts [2] and near-field radiation [3]. However, the real conditions of the contact between the tip apex and the sample surface remain a riddle also its description is often partly a matter of the imagination when using a conventional instrument.

To go beyond these issues, we developed new experimental approaches with their associated modeling of SThM measurement. These approaches were applied to various types of SThM probes and involved measurements on reference bulk and nanostructured samples for various environmental conditions. A combined SThM/ SEM instrument allowing the real-time observation of the shape and the size of the tip, and of the sample surface during experiments was also implemented and used.

Results have confirmed or precised the main parameters of the probe-sample thermal interaction as well as those that define the spatial resolution in SThM, and allowed quantifying the contribution of the various involved heat transfer mechanisms depending on the used probe and the environmental conditions. Results of the investigation of the heat transfer within a free-topography nanocomposite sample comprising in its subsurface polysilicon structures of various thicknesses covered successively by two nanolayers of alumina and thermal silica, and embedded in a silica matrix has moreover clearly demonstrated that the SThM can probe the subsurface of the sample in the case of measurements performed under vacuum conditions and is sensitive to the buried structures. Results using the developed combined SThM/ SEM instrument have allowed to suggest a model for the growth of water film at the sample surface and the formation of the water meniscus at the probe-sample contact. An effect of the electron beam has however been shown to be taken into account while analyzing SPM measurements with such combined instrument.

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