Photo-Activated Thermal Imaging at Sub-Diffraction Resolution

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Conventional non-contact thermal imaging provides temperature spatial maps based on the intensity of infrared radiation emitted by the sample and detected by a microbolometer-based thermal camera under the assumption of grey body radiance. The typically low numerical aperture of collecting Germanium lenses sets a diffraction-limited spatial resolution of ~100-500 µm. However, the nominal limit is effectively worsened to ~1 mm by the thermal waves diffusion in the sample, so that high sensitivity (~0.1°C) temperature mapping with tens-of-microns resolution across extended (mm-/cm-sized) fields of view is not routinely achieved.
Thermal imaging at sub-diffraction resolution is demonstrated here by the development and validation of a super-resolution data acquisition and analysis approach, that combines the photo-thermal effect induced by the sample absorption of modulated focused laser light with the automated a posteriori localization of the resulting laser-induced temperature variations. By the non-linear surface fit of the isolated temperature peaks in the acquired thermal camera frames, light-absorbing and heat-releasing centers get localized and rendered in the final super-resolution image. While best-fit amplitudes code for local temperature values, peak coordinates provide morphological information on the absorbing sample with a resolution assigned by the ~10-µm excitation laser-spot size.
We initially validate the proposed approach on synthetic ink samples. By comparing our results with conventional transmitted-light images of the same structures, we confirm accurate imaging capability at 60-µm resolution. On the adopted setup configuration, we prove therefore a resolution gain of a factor of 6 and 20 with respect to the diffraction-limited prediction and the effective (1200±180)-µm resolution of our thermal camera in conventional operation. We further perform proof-of-principle experiments on complex biological samples. We image explanted murine skin biopsies treated with Prussian blue 30-nm nanocubes, and provide temperature-based super-resolution maps of the distribution of the absorbing nanostructures across mm-sized tissue sections. Our results suggest potential applications and future impact of photo-activated super-resolved thermal imaging in the characterization of the homogeneity, morphology and functional state of both biological tissues and synthetic materials.