A device to inspect a skin cancer tumour in the terahertz range, transferring the image into the infrared

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The sensitivity of the THz radiation to water, which is one of the most important components of the biological tissue, can be used in practical schemes of visualizing a tumour. Namely, the water molecules absorb throughout the entire THz band (0.1–10 THz) [1], and the water content in cancerous tumours is higher than in normal tissues. One can think of a setup using the transmission geometry (see Fig. 1), which would normally involve *in vitro* study of a thin, clinically prepared tissue sample. In this approach, the necessary contrast for imaging the tumour and discerning it from the normal tissue is provided by enhanced water content in cancer cells. Otherwise, the fact that the THz waves cannot penetrate moist tissue motivated for the development of imaging in the reflection geometry, better suited for investigations *in vivo*, the most straightforwardly in relation with the skin cancer (Fig. 2). The reflectance of THz radiation, and hence the contrast in imaging the area with cancer cells, is enhanced as the water temperature in them increases [2,3,4,5]. To heat water in cancer cells, the gold nanoparticles (GNPs) can be premediately delivered therein; corresponding techniques are known [6,7]. Then the tumour is non-invasively treated by irradiating with near-infrared (NIR) laser beam at ~650–1350 nm wavelength (this is the so-called "therapeutic window" where light has its maximum depth of penetration into the tissues). Under irradiation, the surface plasmons are excited in the GNPs; on dumping out the plasmons, the water is heated around the nanoparticles in cancer cells. In consequence, the cancer cells start to reflect the incident THz radiation even more efficiently. The feasibility of the THz imaging of the body with skin cancer in reflection geometry have been demonstrated in [8].

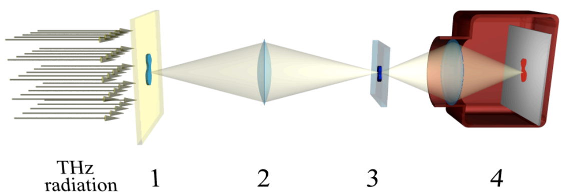

Fig. 1. Transmission mode for *in vitro* studies: 1 – a tissue sample, 2 – the THz objective (high resistivity float zone silicon, high density polyethylene or Teflon®), 3 – THz-to-IR-converter, 4 – highly sensitive IR camera

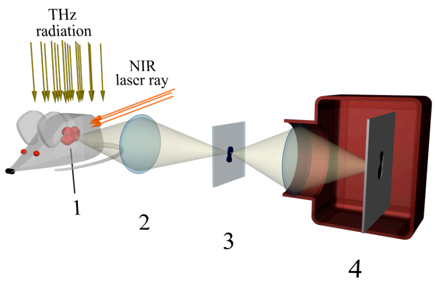

Fig. 2. Reflection mode for *in vivo* imaging with a usage of the near-infrared (NIR) laser for excitation of surface plasmons in GNPs inside a tumour (for heating water in cancer cells): 1 – tumour, 2, 3, 4 – the same as in Fig. 1

The nature of the THz radiation source to be used is not crucial for the present contribution; we note, nevertheless, that a possible design for such source was suggested in [9], having, as its working element, gold nanobars or nanorings which ought to be irradiated by microwaves in order to emit THz photons with energies within the full width at half maximum of the longitudinal acoustic phononic density of states of gold (16 –19 meV, i.e., 3.9 – 4.6 THz), with a maximum at about 4.2 THz (17.4 meV). In Ref. [10] it was shown that gold nanorhombicuboctahedra could be used as emitters of radiation at 0.54 and at 8.7 THz, important for the THz imaging of human skin cancer, in the context of findings of Ref. [11, 12] and possible impact on the improvement of spatial resolution.

The essential element for the hence suggested THz inspection device is the THz-to-infrared converter consisting of a layer (a matrix) of GNPs deposited onto (or, embedded into) a substrate, transparent in both THz and IR ranges. In both setups outlined by Figs. 1 and 2, the image (in the THz rays) originating from the tissue sample (position 1) is projected by the objective (position 2) onto the two-dimensional THz-to-IR-converter (position 3). The GNPs, on irradiation with THz rays, convert the energies of THz photons into heat, being so the bright spots for subsequent detection by a highly sensitive IR-camera (position 4). In this quality, commerciably available devices can be considered, which allow nowadays the temperature sensitivity of 14 to 50 mK [13,14].

A preliminary description of the scheme has been outlined by us in Ref. [15]. The present analysis reiterates the physical mechanism, which includes an excitation of the Fermi electron via an adsorption of a THz photon, and the subsequent relaxation with releasing a longitudinal phonon. The constraints imposed by size and shape of the nano-objects are discussed, along with the manifestation of the momentum and energy conservation laws in the preference for different channels of relaxation. Technically, calculations are done of the THz irradiation power needed to be delivered in order to enable detection of a thermal image developed on the converter by IR cameras. The static distribution of temperature around a

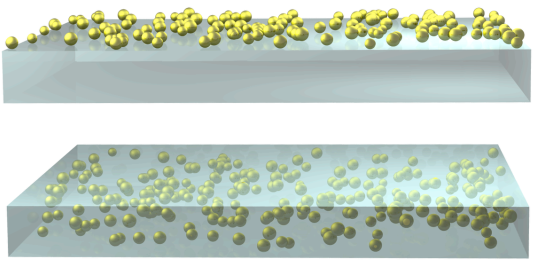

Fig. 3. Schemes of the THz-to-IR converter: above – in the form of a substrate transparent in THz wavelength range with GNPs; below – in the form of a matrix transparent in THz wavelength range with embedded GNPs

GNPs of different sizes embedded in a substrate (specifically, Teflon® and silicon have been considered) was calculated, along with dynamical onset of the temperature, in order to estimate the size and reaction time of bright spots being created in the converter, and thus to judge about the latter's spatial resolution and reaction time.

Concerning the realization of the THz-to-IR converter, two schemes shown in Fig. 3 may come into discussion. That in the form of a thick film with embedded GNPs (Fig. 3, lower scheme) seems preferable over single-layer deposition (Fig. 3, upper scheme), because it allows to achieve larger "projected" density of GNPs per surface unit, avoiding at the same time to place them too closely.

The obtained theoretical results demonstrate that the suggested approach can be realized with the THz-to-IR converter made of Teflon® film of ~ 0.1 nm thickness, containing GNPs of ~10 nm diameter. With this, the suggested design is only waiting for practical tests.

Considering a possible impact in medicine, one can recall that, in contrast to X-rays, the THz radiation is not ionizing and not harmful to living organisms. The development of practical THz imaging setups is one of the "hottest" areas in nanotechnology-supported modalities for the cancer diagnostics. The THz diagnostics in reflection geometry allows for non-invasive *(in vivo)* THz imaging of skin cancer's surface features. It could be performed *in situ*, without time losses on standard *in vitro* histological tests. Other areas of dermatology, where the THz imaging in reflection geometry might be advantageous, are (*i*) skin burns and wound inspection through bandages, and (*ii*) monitoring the treatment of skin conditions (like psoriasis), since this allows to avoid the direct contact with the skin as *e.g.* under ultrasound investigation. Even if the THz radiation is strongly absorbed by water and does not penetrate tissue to any significant depth, the use of the transmission geometry and clinically prepared tissue samples (both of inner organs and the skin) may offer an interesting extension to established techniques. One can mention in this relation that the THz imaging is less costly than, for instance, the magnetic resonance study.

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