

FRAUNHOFER INSTITUTE FOR CERAMIC TECHNOLOGIES AND SYSTEMS IKTS

QUALITY ASSURANCE AND PROCESS CONTROL IN IONIZING RADIATION PROCESSES BY MULTIDIMENSIONAL DOSIMETRY

A dosimetry system based on radiation-sensitive ceramic phosphors



Some of today's specific dosimetry applications require a dosimeter which approaches the real product surface as closely as possible and follows its 3D surface, especially when photon or electron energies lower than 500 keV are used. Such a dosimeter would allow (1) the optimization of radiation processes in terms of lateral or depth dose distribution and (2) provides instant dose measurement results.

To address these aspects, Fraunhofer IKTS presents a versatile dosimetry system based on ceramic phosphors. It offers its users the opportunity to coat the surface of any shaped products, including inner sides of containers and bottles and derive dose maps automated and instantaneously after radiation exposure.

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A dosimetry system based on radiation-sensitive
ceramic phosphors

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1. Why – Overcoming “unavailabilities” for specific dosimetry applications

Product treatment by means of ionizing radiation (electron beam, x-ray, Gamma) is an important health- and security-related technology in many fields like food safety, seed and raw material disinfection in agriculture, crosslinking of wires, cables and tubing, curing of coatings as well as sterilization of pharmaceutical products and packaging. As numerous as the products as various is the purpose of the radiation treatment: sterilization, “in-activation” of biological species to meet phytosanitary regulations or to produce vaccines, improvement of (polymer) material properties through irradiation-induced crosslinking/branching/scissioning, semiconductor enhancement. Common to all applications of ionizing radiation is the key role of radiation dosimetry, the assessment of the ionizing radiation dose absorbed, for quality assurance and process control. The dose measurement is of prime importance to conclude if a product has been sufficiently and efficiently exposed to radiation or not.

State-of-the-art dosimetry systems rely on 2D dosimeter forms like tailored polymer stripes or stickers. While in some applications pellets are used which carry a radiation-sensitive film, others require to fix dosimeter films on fissured surfaces. First, this complicates the evaluation of the absorbed dose on complex (3D) product surfaces, as the dose is not measured on the product surface but in the 2D dosimeter, which does not necessarily follow the product surface. For these scenarios a dosimeter is needed that approaches and follows the product surface as precisely as possible.

Second, in other dose measurement scenarios a point dose or dose profile measurement inside the product is needed. Thus, the dosimeter needs to be embedded within the product. Furthermore, present-day dosimetry systems are time-consuming in use as they do not lead to instant results in a continuous process and dosimetric sensitive materials are usually too thick to allow optimization of radiation processes when irradiated with e.g. low energy e-beams.

Fraunhofer IKTS offers a dosimetry system based on radiation-sensitive ceramic phosphors that eliminates these drawbacks.

2. What – Dosimetry based on ceramic phosphors

The solution Fraunhofer IKTS offers, uses a ceramic phosphor powder as dosimeter material. As shown in Figure 1A this optically active material shows a luminescence upon excitation with near-infrared light. The decay time of this luminescence is sensitive to ionizing radiation, i.e. it shortens with increasing dose of the applied radiation, thus allowing dose determination (Figure 1B). The dynamic range of the luminescence response ranges from 0 to 30 kGy with the highest sensitivity between 0 and 10 kGy (Figure 1C).

As the dosimeter material is inert, various deposition techniques are possible (Figure 2): the μm -sized phosphors can be embedded into other materials which gives access to dose information inside the products (see section 4). Alternatively, the

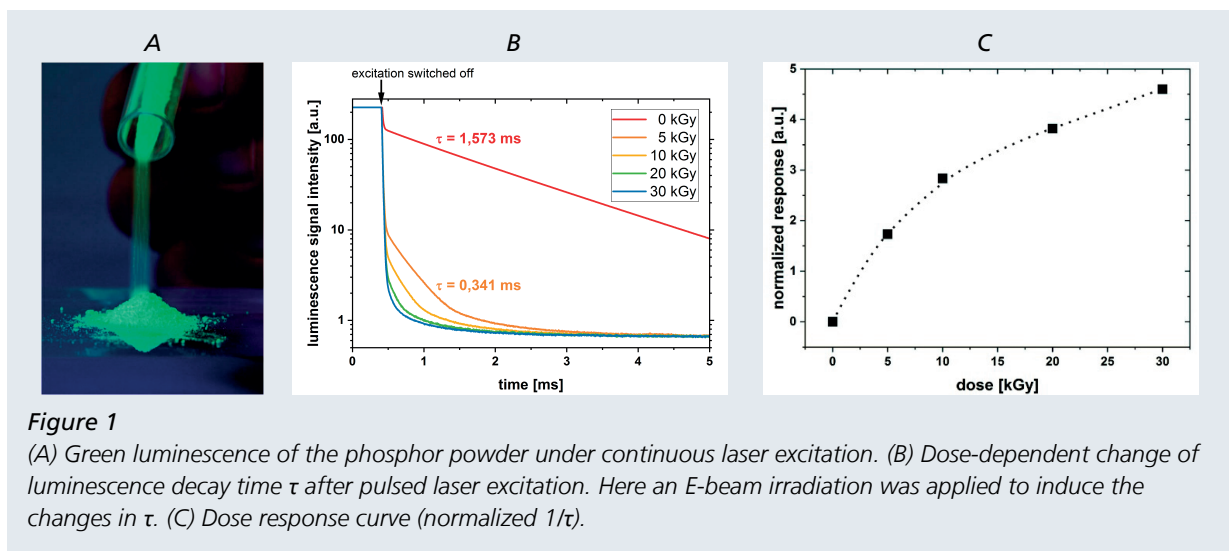




Figure 2
Examples of deposition techniques for the dosimetric active ceramic phosphor. From left to right: embedding, nozzle printing, dip coating, spraying.

phosphor powder is integrated into polymer matrices to formulate inks and lacquers which allows labelling of specific surface areas or coating of entire 3D product surfaces prior to radiation exposure. Whichever way is applied, the user obtains test product bodies equaling the original product but equipped with the dosimetric functionality. These test products can then undergo the radiation exposure during installation qualification or for routine process quality assessment. Interrogation of the applied dose on/inside the test products may follow automated inline.

This read-out of the dose-dependent change in the phosphor's luminescence after irradiation can be performed with different set-ups depending on the spatial resolution needed in a user's application. The competences of Fraunhofer IKTS comprise adoption of optical measuring heads from luminescence detection of single phosphor particles (spot size of a few μm) to averaging information in mm-size spots.

3. How – Realization in 0D, 1D, 2D and 3D

0D – Individual phosphor particles or printed dots

The luminescence decay information of individual phosphor particles can be measured and hence an applied dose at their specific spatial position can be derived (Figure 3). Thus, if the phosphor particles are embedded into products or polymeric/wax twins of products (retaining the radiation penetration properties of the original product), access is gained to dose maps or depth dose profiles inside the product.

Fields of application comprise depth dose profiles in bulk dry goods.

A much simpler 0D application with respect to spatial resolution is the deduction of dose information from reading-out printed dots of dosimetric-active

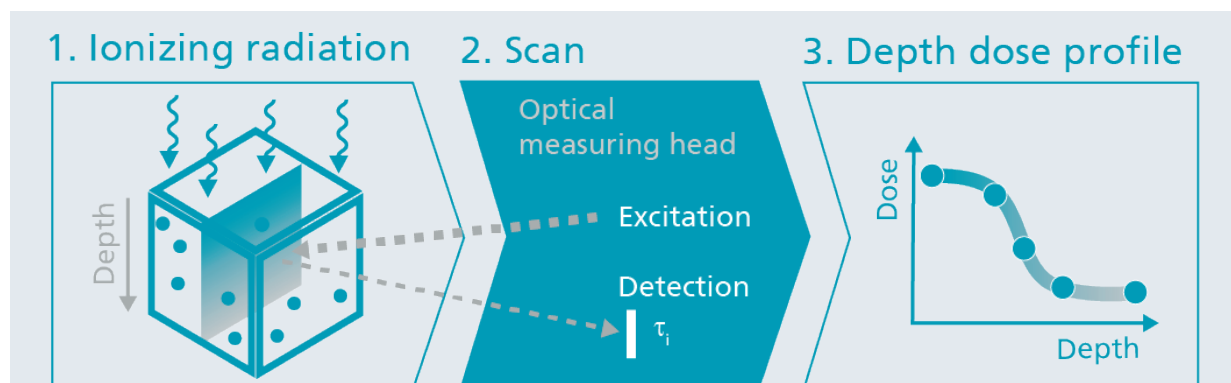


Figure 3
Schematic presentation showing the acquisition of a depth dose profile with the help of phosphor particles embedded inside the product (cubic product for ease of depiction). After radiation exposure the embedded phosphor particles are scanned to read-out their individual decay times and derive a dose information. Finally, the particles' depth positions are correlated with this dose in the depth dose profile.

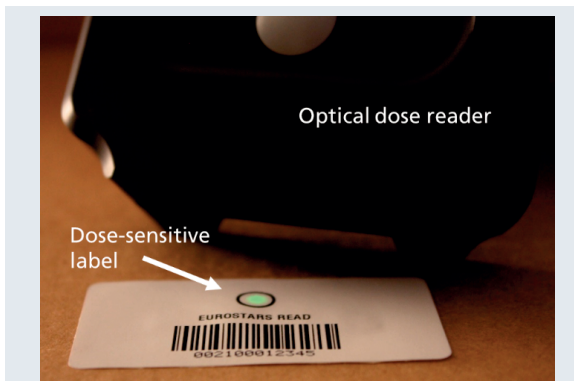


Figure 4
Paper label comprising barcode and radiation-sensitive dot. The latter shows a green luminescence under laser excitation by the optical dose reader. In a single step, both, the luminescence decay time (providing the dose information) and the information encoded in the barcode are read-out.

ink on a dose label comprising also a dosimeter identifier (e.g. barcode, Figure 4). Here, simultaneous reading of absorbed dose and barcode for coding product and dosimeter information in a single shot from a hand-held optical device is what gives this solution its charm.

1D – Fibers

The phosphor particles can be attached to the surface of fibrous materials to enable dose read-out along the fiber surface. The concrete realization of the particles' binding to a certain fiber material strongly depends on possible specific physical or chemical interactions between these two materials. Fraunhofer IKTS has a fund of experiences in the specific functionalization of surfaces.

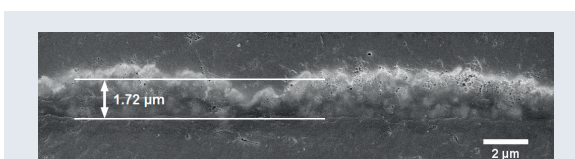


Figure 5
Scanning electron microscope image of a dip-coated, 1.72 μm thin layer of lacquer containing phosphor particles on a polymer foil.

Polymer fibers which are interwoven to meshes for medical scaffolds pose an example of use. Therein the dosimetric active fibers could be used to monitor the sterilization process of the scaffolds.

2D – Flat surfaces

2D flat surfaces can be homogeneously coated with a thin layer of lacquer containing the phosphor particles, e.g. by dip coating. Well defined coatings with layer thicknesses of a few micrometers only can be realized (Figure 5). Scanning read-out of the optical response of this dosimetrically active coating permits surface dose assessment in 2D dose maps. This allows (1) optimization of radiation processes in terms of lateral dose distribution and (2) provides instant dose measurement results.

3D – Complex curved surfaces

To derive surface dose maps on complex, 3D-curved products they can be entirely coated (interiorly and externally) with a thin layer of phosphor containing lacquer prior to irradiation. Spray and dip coating are named as examples of coating techniques realized so far at Fraunhofer IKTS. Using an automated read-out system (title page) the dose information can be acquired instantaneously point by point from this 3D surface (Figure 6). This is currently not possible with any other dosimetry material available on the market. In the dose map areas of minimum and maximum dose become easily visible, which are important in the process qualification of industrial radiation processing.

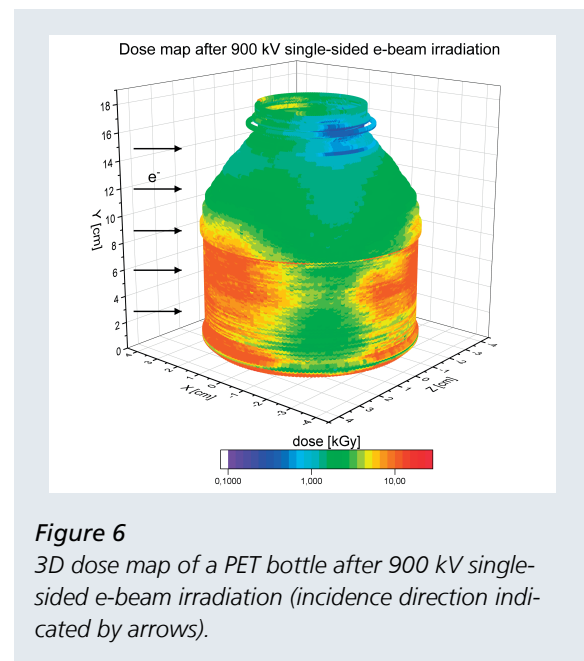
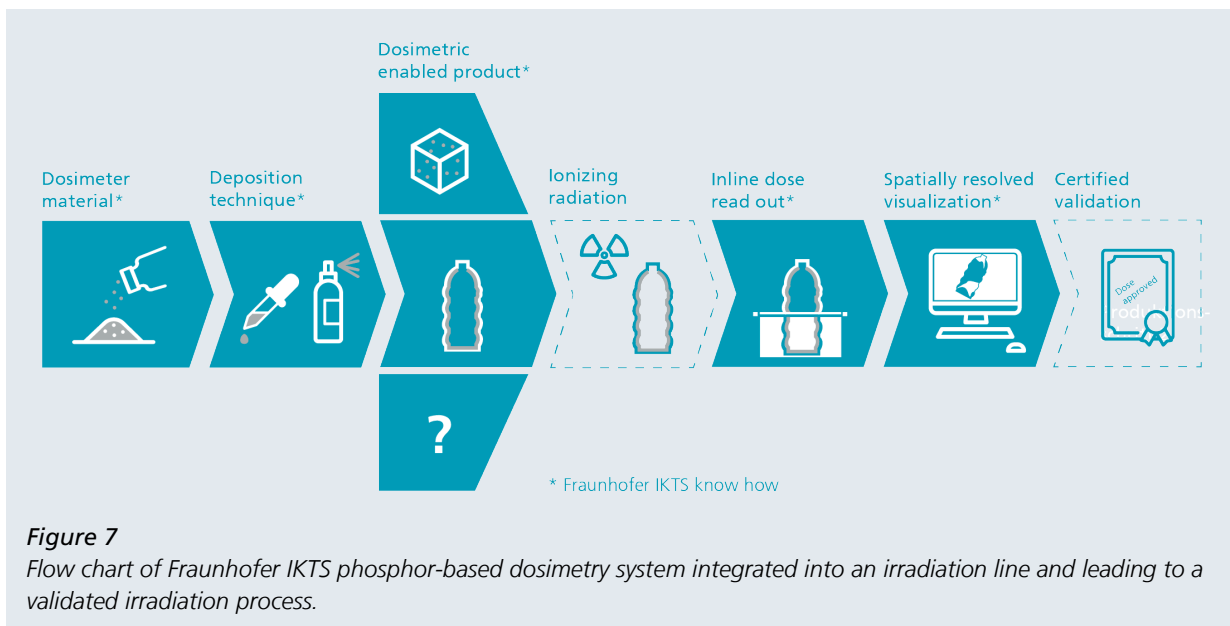


Figure 6
3D dose map of a PET bottle after 900 kV single-sided e-beam irradiation (incidence direction indicated by arrows).



4. The offer of Fraunhofer IKTS

Based on ceramic phosphor particles Fraunhofer IKTS offers a dosimetry equipment that can be adopted for individual dosimetry applications from 0D to 3D. Products and services offered (Figure 7):

- Preparation of phosphor powder of needed grain size
- Development of a coating technique to “decorate” 1D to 3D products with phosphor particles with the needed surface coverage; if needed, integration into an existing production line
- Preparation of phosphor containing inks, lacquers, pastes appropriate for a chosen coating technique and optimized for required phosphor layer thickness, product adhesion and chemical compatibility with the product
- Preparation of phosphor containing twin products
- Development of a dose read-out device adopted to geometry, dimensions of a product and required spatial resolution of dose read-out. Both hand-held devices and fully automated, production line integrated interrogation systems including interfaces to the process control can be realized.
- Traceable dose reference measurements are offered as well as development of dosimetry software to complete the dosimetry system which fulfills the radiation industry requirements and can be validated (FDA 21CFR part 11 and 820, ISO 11137) as a whole.

5. Conclusions and advantages for customers

With a dosimeter based on radiation-sensitive phosphor particles dose measurements are enabled on products, where today’s dosimeters are inapplicable due to their low contour accuracy and lateral dose resolution. Where the radiation-sensitive phosphor particles are applied, dose information can be acquired at individual spots, along lines, on flat surfaces as well as on curved or structured product geometries. Thereby, the phosphors are incorporated as single micro-particles or embedded in a thin-film coating. Thus, the dose information is accessible for instantaneous and automated read-out, saving costs and man-power as well as providing certified quality assurance.

The Fraunhofer Institute for Ceramic Technologies and Systems IKTS conducts applied research on high-performance ceramics. The institute’s three sites in Dresden and Hermsdorf (Thuringia), Germany, collectively represent Europe’s largest R&D institute dedicated to the study of ceramics.

As a research and technology service provider, the Fraunhofer IKTS develops advanced high-performance ceramic materials, industrial manufacturing processes as well as prototype components and systems in complete production lines up to the pilot-plant scale. In addition, the research portfolio also includes materials diagnostics and testing. The test procedures in the fields of acoustics, electromagnetics, optics and microscopy contribute substantially to the quality assurance of products and plants.

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