MPD technology for tribology applications

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Abstract

The new ultra-sensitive MPD technology, already employed successfully in biomedical applications, has such a high sensitivity that it is possible to use extremely low level radioactive materials, below licensing requirements and presenting no health hazard. It can now be employed in tribology, both as a research tool and in industrial and consumer applications. We discuss a few straightforward tribological applications of the MPD technique.

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1. Introduction

Since the early days of nuclear technology, the use of radioactive tracers has seemed a very attractive way to study processes of wear and corrosion. [1-3]. The nondestructive, remote and mezzoscopic imaging possibilities of monitoring and surveillance are an obvious advantage of radioactive tracers. Unfortunately, the difficulties and dangers associated with dealing with highly radioactive materials impeded widespread use of this technique. The activity of materials under observation was too high even for laboratory tests, not to mention for use in routine maintenance.

This situation has changed in the last few years with the development of MPD (Multiple Photon Detection) technology. This new methodology, already employed successfully in biomedical applications, has such a high sensitivity that it is possible to use extremely low level radioactive materials, below licensing requirements and presenting no health hazard. It can now be employed in tribology, both as a research tool and in industrial and consumer applications. In the following we give a short introduction to MPD and mention a few possible uses in tribology.

2. Brief review of MPD technology

The improvements in question are enabled by the ultra-sensitive MPD technique [4-6]. This technique is applicable to more than 60 radioactive isotopes, having a broad range of lifetimes. The MPD technique is further enhanced by the use of radio-labeled fullerenes [7, 8]. MPD technology and its applications to tribology problems are a result of collaboration of Dr. A.K. Drukier and his group at Biotraces Inc. with the group of Dr. B. Coursey, National Institute of Standards and Technology (NIST) and with Dr. L. Stodolsky, Max Planck Institute, Munich, Germany.

The MPD technique relies on selected radioisotopes which decay with emission of two high-energy photons. The MPD technique, which combines coincident photon detection with sophisticated signal processing methods, improves sensitivity by about four orders of magnitude compared to previous methodology and achieves 1fCi sensitivity for the ^{125}I label. MPD readout electronics selectively count only those events which are compatible with the decay signature of a chosen isotope *i.e.*, different isotopes can be simultaneously and independently employed. The detection limit for classical radiometric methods is approximately one million atoms of label. MPD marks a new milestone in sensitivity; detection of less than a hundred atoms and sub-zeptomole ($< 10^{-21}$ mole) amounts of material is possible. Even for applications requiring a large throughput, the MPD technique needs less than 1 pCi of an isotope, *i.e.*, about a thousand times less activity than conventional methods.

Detector Sensitivity: Measurements of serial dilutions of iodinated avidin-polyHRP with ^{125}I label show excellent linearity (within 1%) over nine orders of magnitude of label concentration (see Figure 1). The reproducibility for a 10 pCi source is within 1%. For a few pCi source we observe excellent signal to background ratio (S/B>10) with counting times of a few minutes.

Spatial resolution of the MPD Imager: We obtain sub-millimeter resolution without loss of sensitivity. We compared our MPD Imager to a commercial phosphor imager at a very low surface activity of 10 pCi/cm^2. Figure 2 shows the test pattern (Figure 2a), the images obtained with MPD Imager (Figure 2b), and a Molecular Dynamics phosphor imager (Figure 2c). With a 48 hour

exposure the phosphor imager can detect the 3 mm pattern, although the background is quite hig The phosphor imager only partially resolves the 2 mm pattern, while the 1 mm pattern is n measurable. The MPD Imager resolves the 1 mm pattern with S/B ratio of about 10 and in a tin much shorter than used by phosphor imager.

3. Applications of proposed method

Below we will briefly discuss three possible examples of application of MPD techniques in tribolog For each application, we give performance estimates which are based on sensitivity and spati resolution already achieved.

Proper wear monitoring may considerably decrease the cost of maintenance and prevent disastro accidents. Currently maintenance and repairs are very expensive, *e.g.*, for the pumps in underwat gas and oil pipelines, pumps in pipelines of nuclear plants, large diesel ship engines and many oth applications.

The basic principle of radioactive wear monitoring is that the parts subject to wear are doped wi a small amount of a radioactive tracer. As the wear particles are removed from the part or surfa in question into an ambient fluid, they pass by and are accumulated by a filter. The filter is monitore continuosly or periodically by an MPD detector; the level of activity of the filter is proportional t the wear. Optionally, the radioactive material is shielded by a protective layer, and the appearanc of the tracer in the filter is a signal of a wear. The following examples illustrate the possib embodiments of wear surveillance systems.

Bearing wear monitoring: The radioactive tracer, for example ^{60}Co, may be implemented in a thi layer under the protective coating. ^{57}Co and ^{65}Zn would be other good candidated with shorter li times than ^{60}Co. When the protective coating wears through, particles with radiolabel are washe out into the lubricating oil, absorbed by a magnetic or other filter, and detected by an MPD-detecto With the presently achieved sensitivity of the detector of 1 pCi, the total activity of the monitore bearing can be substantially below 1μCi, which is a license exempt level for ^{60}Co. More than one typ of tracer can be used to label different bearings which are simultaneously monitored in this case b one MPD detector.

Pipe corrosion monitoring: A possible detector for pipeline corrosion control is shown in Figure The inside surface of the pipes is coated by a layer with a radioactive tracer. The corroded particl are washed out by gas or liquid flow and accumulated in the filter. The activity of the filter periodically measured by an MPD detector.

Thin film thickness monitoring: If a thin film is doped uniformly with a radioactive tracer, the activi of a unit area of the surface is proportional to the thickness of the film. This makes the MPD Imag an instrument for thin film thickness observation. As mentioned above, the spatial resolution of th MPD Imager may be as small as 1 mm. The activity can be measured if necessary with 1% precisio A possible setup for thin film control is shown in Figure 4. The surface coated by this film is scanne by an MPD Imager. To achieve 1% precision, the activity of 1 mm^2 area should be on the order 30-40 pCi, which means that the overall activity of the sample 5 cm x 5 cm may be as low as 100 nC

which again is a license exempt level of activity.

MPD compatible isotopes have a very broad range of lifetimes. Short-life-time isotopes can be preferably used for quality control in production processes. In ten half-life time periods the activity of a radioactive isotope decreases 1000-fold. Thus, if an MPD compatible isotope is used, the activity becomes negligibly small when the product is in use. For maintenance uses, long-lifetime isotopes will be preferable. The decrease of activity with time in this case can be easily accounted for by software corrections and periodic self-calibration of the instrument.

We have mentioned only a very few of the simplest and most straightforward tribological applications of the MPD-technique. Many variants can be envisaged. For example, methods with special non-radioactive tagging which can later be derivatized by radioactive labels are also possible. In the case of pipeline corrosion monitoring, for example, the label added to the pipe coating may be non-radioactive. Then this label will be collected from the gas or liquid by a filter; the filter will be removed from the pipeline, derivatized and measured by an MPD-detector. This method does not require the presence of radioactive materials in the coating, but presumes a sampling procedure. The MPD-technique can be used also in combination with other methods of analysis, like TLC, HPLC, and so on. In most cases the use of MPD technology in combination with existing analytical methods results in increasing the sensitivity hundredfold.

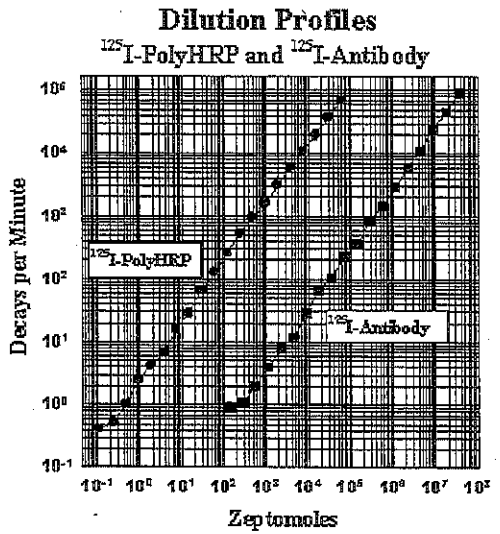

Figure 1. Serial dilutions of ^{125}I-Antibody and ^{125}I -Av-polyHRP showing the excellent sensitivity and dynamic range of MPD down to the 0.1 zeptomole level.

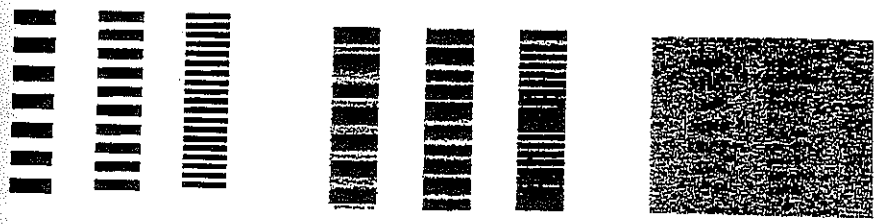

Figure 2. Imaging of low activity bar patterns (10pCi/cm^2) using the MPD Imager and a commercial phosphor imager

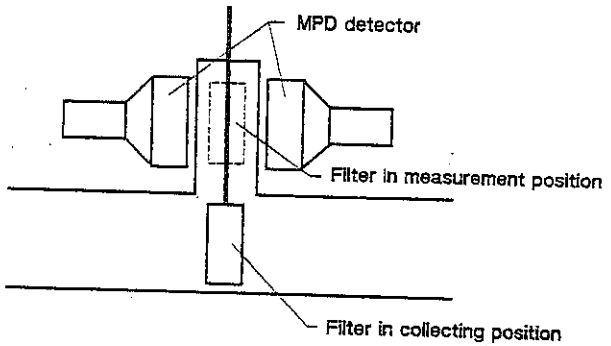

Figure 3. The schematics of the proposed implementation of MPD-based method for pipe corrosion measurements.

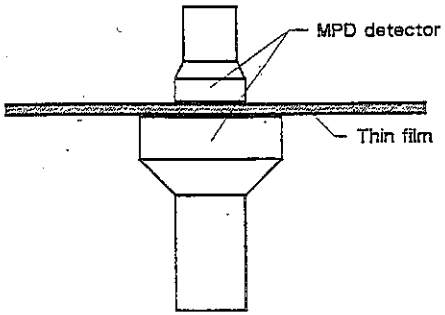

Figure 4. The schematics of proposed MPD-based apparatus for thin film quality testing.

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