TeO_2 scintillating crystals growth and properties

Ioan Dafinei[a*], Marcella Diemoz[a], Mauro Fasoli[b], István Földvári[c], Egidio Longo[a], Federico Moretti[b], Ágnes Péter[c] , Fabrizia Somma[d], Anna Vedda[b]

[a] *Università "La Sapienza", Dipartimento di Fisica and INFN Sezione di Roma, P-le Aldo Moro 2, 00185-Roma, ITALY*

[b] *Università Milano - Bicocca, Dipartimento di Scienza dei Materiali,Via Cozzi 53, 20125-Milano, ITALY*

[c] *Research Institute for Solid State Physics and Optics, 29-33 Konkoly-Thege M. Street, Budapest, HUNGARY*

[d] *Università degli Studi Roma Tre – Dipartimento di Fisica, Rome, ITALY*

Abstract

The advantages of using hybrid detectors (scintillating bolometers) in rare event searches like Double-Beta Decay are discussed. The possibility to produce scintillating TeO_2 crystals is emphasized and the results of optical transmission, X ray excited steady-state luminescence and thermo-luminescence measurements performed on pure and doped TeO_2 crystals are presented.

1. Introduction

Bolometers are often the key piece in experimental apparatuses built for the study of rare event processes like double-beta decay (DBD). In such processes the energy is delivered at extremely small rates, which explains the necessity of using detectors of very low energy threshold and very low background. The case of tellurium dioxide (TeO_2) is a unique combination of bolometer and source since the isotope ^{130}Te is DBD active. More, the 33.87% natural abundance of ^{130}Te avoids the expensive enrichment procedure typical for other elements.

One of the main problems of DBD experiments is the necessity to reduce as much as possible the background, and hybrid detectors able to distinguish events due to other processes may be a solution. The present work gives the preliminary results of tests made on pure and doped TeO_2 samples recently grown in the frame of an R&D activity aimed at producing scintillating TeO_2 crystals [1].

2. Experimental data and discussion

Growing doped TeO_2 crystals is generally considered a very difficult task. The asymmetric covalent Te-O bonds in paratellurite (TeO_2) limit to

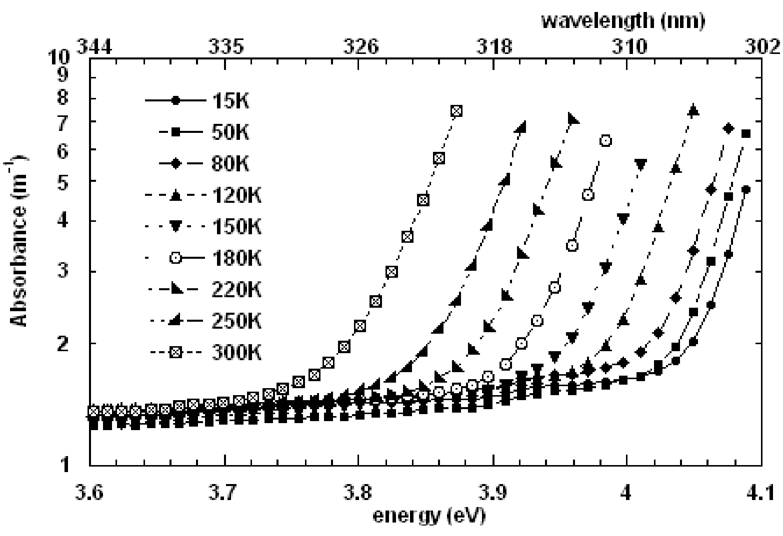


Fig. 1. Temperature dependence of TeO_2 crystal absorbance in the absorption band edge region.

* Corresponding author. Tel.: +39-0630483146; fax: +39-0630486119; e-mail: ioan.dafinei@roma1.infn.it

only a few the number of possible candidates to substitutional incorporation in TeO_2 lattice. Further selection criteria reduce the list of possible candidates for scintillation activator in TeO_2 to: Mg, Mn, Nb and Zr. In spite of various difficulties, doped TeO_2 crystals were successfully grown with doping elements concentration of 10^{-4}-10^{-3} mol/mol in the melt [1]. Samples prepared from these crystals and different tests are on the way, aimed at understanding the scintillation mechanism and find the ways to enhance the scintillation light yield of doped TeO_2.

As TeO_2 crystals are currently produced for acusto-optic devices, special attention is given in literature only to those optical properties connected to this application. The study of optical characteristics (transmission and reflection) near and above the fundamental absorption edge at low temperatures was carried out only till 80 K [2] and experimental results [2, 3] do not allow for a definitive interpretation of electronic band structure for TeO_2 crystal. It is also missing from litterature a detailed study of the agreement between calculated electronic structure [4] and optical transmission measurements.

Preliminary optical transmission measurements were performed on pure and doped TeO_2 slices prepared in this work using a Perkin Elmer *Lambda900* spectrophotometer and a Leybold *RDK10-320* (Tmin=12K) cryostat. As figure 1 shows, the absorbance spectra show a temperature dependence typical for an indirect band structure. A detailed analysis of low temperature transmission measurements is on the way.

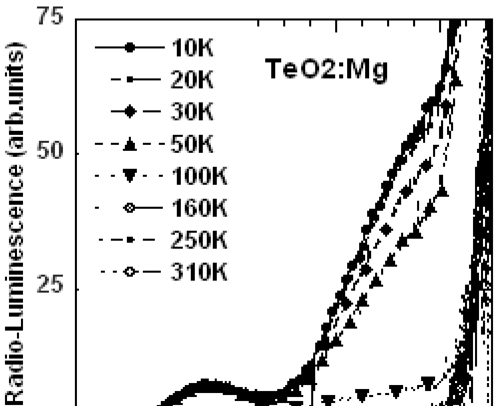


Fig. 2. Typical temperature dependence of radio-luminescence spectrum of pure and doped TeO_2 crystal samples studied in this work.

Steady state X-ray excited radio-luminescence and thermo-luminescence measurements were performed on a home made measuring set-up consisting of a vacuum chamber (10^{-8} Torr) and a cryostat allowing for working temperatures in the range from 8K to 320K. In situ X-ray irradiation with an X-ray tube (Philips 2274) is possible through a Beryllium window. Emitted light (both for radio and thermo-luminescence) is read by a CCD (Jobin Yvon Spectrum One 3000) coupled to a monochromator (Jobin Yvon Triax 180).

The sharp luminescence increase observed above 1000 nm is an artifact related to the spectral correction at the high wavelength limit of the detection range.

Radio-luminescence spectra presented in this work were made in identical conditions on crystal samples of identical geometry and mechanical quality (optically polished), i.e. quantitative analysis of luminescence yield for different dopants is possible.

As shown in figure 2 for the TeO_2:Mg sample, the luminescence in TeO_2 suffers a very strong thermal quenching, with a measurable emission only at temperatures under 100K. Luminescence spectra may be divided in two main zones:

- UV-VIS region characterised by a very weak emission at about 345nm most probably of excitonic nature and a larger characteristic emission band centered at 560nm.
- near-IR region characterised by a large unresolved emission band at approximately 900nm

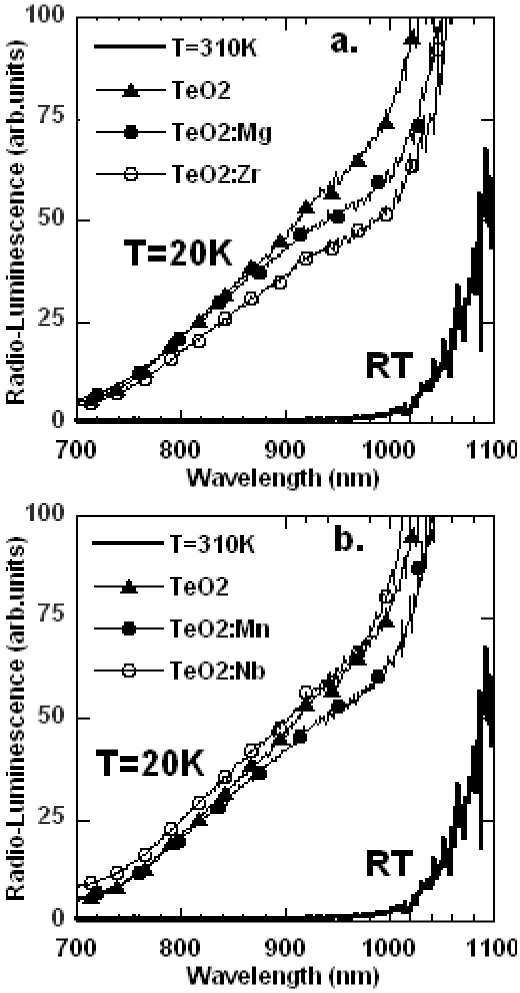
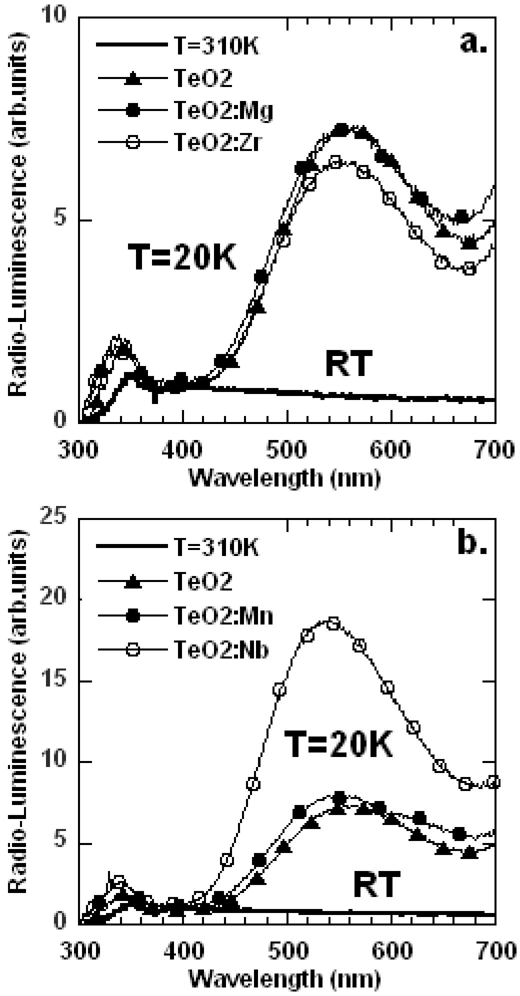


Fig. 3. Radio-luminescence emission of pure and doped TeO_2 samples in near-IR spectral region.

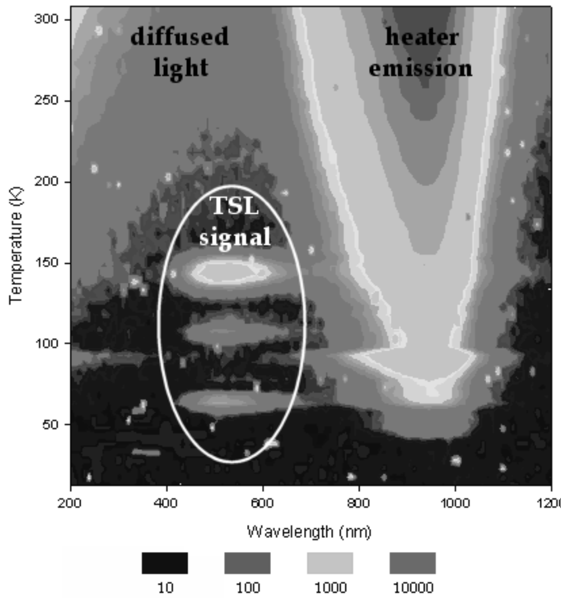
As figure 3 shows, the emission band at 900nm seems to be due to an intrinsic emission center since its amplitude and evolution with temperature practically doesn't depend on the nature of the dopant.

Radio-luminescence spectra in the UV-VIS region of Mg and Zr doped samples are practically identical to spectra obtained for undoped TeO_2 crystal. Nb and Mn doped samples instead, show different spectra



characterised in the case of Nb by a higher intensity band in the spectral region from 500 to 600 nm and by a new emission band centered around 640 nm in the case of Mn. Low temperature photo-luminescence measurements are foreseen to find out the nature of scintillation centers responsible for the emission bands evidenced by X-ray excited luminescence measurements.

Wavelength resolved thermo-stimulated luminescence (TSL) measurements were also performed on all pure and doped TeO_2 aimed at revealing the existence of local centers which may act as traps for secondary carriers generated in the scintillation process thus reducing the global scintillation efficiency. Crystal samples cooled to 10K and exposed to the X-ray tube operating at 30 kV were heated at constant rate (0.1 K/s) while a TSL spectrum acquisition was made with a 5K-temperature step.



In spite of relatively high radiation dose used in these measurements, only Mn and Nb doped samples showed a weak thermo-luminescence. Figure 5 gives the wavelength resolved TSL spectrum obtained in the case of the TeO_2:Nb sample.

3. Conclusion

Successful growth of doped TeO_2 crystals opens the possibility to realize a hybrid detector (scintillating bolometer) able to separate events due to radioactivity background thus enhancing substantially the sensitivity to neutrinoless DBD measurement.

Mn and Nb doping seems a promising way to enhance the scintillation light yield of TeO_2 crystals. Higher dopant concentrations will be tested for a further enhancement of scintillation light yield.

References

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