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STRING

Structured Scintillators for Medical Imaging

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Table of Contents

1 Introduction

This document presents a public summary of the technical achievements and dissemination and use within the project NMP3-CT-2006-032636 STRING-Structured Scintillators for Medical Imaging.

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Public Project Website

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http://www.hitech-projects.com/euprojects/string/

2 Executive summary

1.Quite a few potentially fast emitting compositions have been prepared and YAG:Pr and LuAG:Pr looks the most promising.

2.The energy flow in LuAG:Pr has been unraveled and ways to reduce the afterglow of this material have been identified (partial substitution of Al by Ga).

3.The decay time of LuAG:Pr and YAG:Pr was measured to be about 24 ns.

4.Both ceramic YAG:Pr and LuAG:Pr have a very fast time response (better than the experimental timing resolution, i.e. much faster than 1 ns).

5.Ceramic and almost transparent LuAG:Pr and YAG:Pr can be obtained in sizes suitable for PET applications.

6.Ceramic LuAG:Pr and YAG:Pr scintillators with energy resolution high enough for PET applications have been obtained (energy resolution of single crystalline LuAG:Pr is 4%, ceramic LuAG:Pr has an energy resolution of 10%).

7.New wavelength shifters with spectral absorption matching the d-f emission of Pr ions combining extremely fast decay (τ < 1ns) and high quantum efficiency (> 85%) have been obtained

8.The STRING concept has been realized and shown to work very well in terms of light yield and energy resolution (compared to the scintillating ceramic).

9.The feasibility of applying interference filters on ceramic scintillators has been shown

10.The light yield of ceramic LuAG:Pr and YAG:Pr and of single crystalline LuAG:Pr is too low for PET applications and needs considerable improvements (from 5000 ph/MeV to at least 25000 ph/MeV in the fast 5d-4f transitions). Especially LuAG:Pr would then be a promising candidate for application in PET.

11.Simulation of the temporal behavior of the emission intensity of the STRING stack show too long buildup time of the emission intensity. This can only be improved by even faster organic wavelength shifters, which have not been identified.

12.The project team has done scientific research on a very high level, as shown by a significant number of papers that have been written and will be written, as well as by a number of invited lectures.

13.Additional work still to be done after finalization of the project:

- Research study (co-dopants, processing including annealing, rheological properties and purity of the starting materials) to study effect on ratio 5-d 4f/4f-4f transitions, including measurements on LuAG:Pr ceramics, prepared in the last phase of the project, at Delft University and

- Verification of emission signal simulations of converter/wavelength shifter by time dependent emission measurements on STRING stack at Utrecht University.

3 Project Execution

3.1 Project objectives

State of the art Positron Emission Tomographs require scintillators with a high density (at least 5.0 g/cm³), a high light yield (25000 photons/MeV or more), a short decay time (preferably less than 20 ns), the absence of a build-up in the emission intensity (rise time < 1 ns) and a high energy resolution (smaller than 10%). To completely absorb the high energy radiation, the crystals have a thickness of several mm, this requires transparent scintillators as otherwise many of the photons generated will not reach the photo detectors.

Currently, PET machines use single crystalline materials: in high end time-of-flight PET scanners almost 40000 of them are needed. This contributes significantly to the costs of such scanners. For this reason, it is very worthwhile to look for possibilities to reduce the costs of the scintillators. This will reduce the price of PET machines and increase their proliferation, in this way enhancing the level of medical diagnostics at reduced costs. Cubic materials enable ceramic scintillators (no single crystal growth needed to obtain transparent materials), this results in a reduction in scintillator costs of about 30-40%.

The STRING project aimed at providing ceramic scintillators fulfilling the requirements summarized above (WP1-3). Decay times in the order of 20 ns can be achieved with activator ions emitting in the UV only and this does not comply with the photo detectors used. Therefore, in the project we also looked for organic wavelength shifters, that are adapted to the emission of the scintillators on the one hand and the sensitivity of the photo detectors on the other hand. (WP4). To use the light as effectively as possible, also interference filters are used that prevent UV light, generated by the scintillator from entering the photo detector and wavelength converted light from entering the scintillator (WP5).

Final aim of the project was the so-called STRING stack: a ceramic scintillator with a wavelength shifter, sandwiched between two interference filters and its characterization and assessment of its impact on the image quality in PET (WP5-6).

3.2 Contractors involved

Consortium overview					
#	Participant	Type	Country	Enter project	Exit project
1	Philips Research Aachen	IND	D	M1	M42
2	Forschungszentrum Jülich	RES	D	M1	M42
3	Utrecht University	HE	NL	M1	M42
4	Institute of Physics, University of Tartu	HE	EST	M1	M42
5	Philips Lighting	IND	NL	M1	M42
6	Leiden Institute of Chemistry	HE	NL	M1	M42
7	CNRS (ICMCB)	RES	F	M1	M12
8	Institute for Organic Synthesis and Photoreactivity (CNR-ISOF)	RES	I	M1	M42
9	University of Verona	RES	I	M13	M42

Table 1 : Type: RES (Research organisation), HE (High Education Institute),
IND (commercial manufacturer, Industry),
REP (Service provider e.g. consultant, engineering services), OTH (Other)

3.3 Work performed

Summary of results obtained during the execution of the project.

Quite a few luminescent materials were prepared in which a fast decay is expected. Dopant ions were mainly Ce^{3+}, Pr^{3+} and Nd^{3+}. The main optical parameters are summarized in table I.

Table 2. Luminescence properties of Ce, Pr and Nd in a variety of host lattices. In the columns information is provided on the compositions investigated, the temperature range in which experiments have been conducted, the nature of the emission in the UV and in the visible (+ means observed, + - means weakly observed and - means not observed), the quenching temperature of the fd emission, the bandgap Eg of the host lattice, and the decay kinetics (decay time and rise time for excitation over the bandgap and for direct excitation in the fd state below the bandgap).

Host lattice	**Act**	**Conc. (%)**	**T (K)**	**Emission fd or ff**	**fd_{em} (nm)**	**T_q (K)**	**E_g (nm)**	**T_{dec}(ns) Ex> E_g**	**T_{rise}(ns) Ex> E_g**	**T_{dec}(ns) Ex<E_g**
Phosphates										
YPO_4	Nd	0, 0.05, 0.1, 1, 2, 3,5, 10	10-300	fd (+) ff (-)	190	>300	144	8-12	02-1.5	8
YPO_4	Pr	1	10	fd (+)	240	>300	144			11
YPO_4	Ce	1	10	fd (+)	320	>300	144			29
$LuPO_4$	Nd	0.05,1,6,10	10-300	fd (+)ff(+-)	190	>300	140	6-8	<0.5	6
$LuPO_4$	Pr	1	10-300	fd(+)	235		140			10
$LuPO_4$	Ce	1	10	fd (+)	320	>300	140			
$LaPO_4$	Nd	0, 1	10-300	fd (+)	190		153			5
$LaPO_4$	Pr	1	10-300	fd (+)	245		153	12-20+	<0.5	12
$LaPO_4$	Ce	2		fd (+)	325		153			
$Ba_3Lu(PO_4)_3$	Pr	1	10-300	fd (-)						
$Ba_3Lu(PO_4)_3$	Nd	1		fd (-)						
$Sr_3La(PO_4)_3$	Pr	1		fd (-)						
$Sr_3La(PO_4)_3$	Nd	1		fd (-)						
Halides										
$LiYF_4$	Ce	0.1	10	fd(+)	310		~110			29
$LiYF_4$	Pr	1	10	fd(+)	220		~110			19
$LiYF_4$	Nd	0.5, 2	10	fd(+)	180		~110			15
$LiLuF_4$	Pr	1	10-300	fd(+)	220		~110			18
$LiLuF_4$	Nd	1	10-300	fd(+)	180		~110			
BaF_2	Nd	0.2	10	fd(+), defect			~120			
CaF_2	Ce	0.015	10	fd(+)	320		~110			
CaF_2	Nd	0.05	10	fd(+)	180		~110			
CaF_2	Pr	0.05	10	fd(+), ff(+)	230		~110			
$NaCaYF_6$	Pr	0.05	10	fd(+)			~110			
SrY_2F_8	Pr	0.05	10	fd(+)			~110			
Rb_2NaYF_6	Nd	1	10	fd(+)			~110			
NaCl	Ce	0.1, 1	10-300	fd (+-)	320		155			
NaCl	Pr	0.1, 1	10-300	fd (+-)	260		155			
$SrCl_2$	Ce	0.1, 1	10-300	fd (+)	340					
$SrCl_2$	Pr	0.1, 1	10-300	fd (+)	240					

Host lattice	Act	Conc. (%)	T (K)	Emission fd or ff	fd_{em} (nm)	T_q (K)	E_g (nm)	T_{dec}(ns) Ex> E_g	T_{rise}(ns) Ex> E_g	T_{dec}(ns) Ex<E_g
Aluminates										
YAG	Ce	0.05,0.5,1,3	10-300	fd (+)	540	550	178			65
YAG	Pr	0.1,0.3,1,3	10-600	fd (+)	320	300	178			21
YAG	Nd	1	10-300	fd (-), ff (+)						
YAG	Sc		10-300	defect	270	<300	178			~1000
LuAG	Ce	1	10-300	fd (+)	530		~175			
LuAG	Pr	0.1, 1	10-300	fd (+)	310	>400	~175			23
$LaAlO_3$	Pr	1	10-300	fd (-)			211			
$YAlO_3$	Pr	1	10-300	fd (+)	240	>500	158		< 1	20
Silicates										
Y_2SiO_5	Ce	0,0.01,0.2,1,5	10-300	fd (+)	400	>300	~180	35 +long	~1	34
Gd_2SiO_5	Ce	0,0.01,0.2,1,5	10-300	fd (+)	420	>300	~180		30	
Lu_2SiO_5	Pr	1	300	fd(+)	270		~180			16
$Lu_2Si_2O_7$	Pr	1	300	fd(+)	270		~180			17
$Ca_3Sc_2Si_3O_{12}$	Pr	1, 10	10-300	fd (+)	310		~180			26
$Ca_3Sc_2Si_3O_{12}$	Nd	1, 6	10-300	fd (-)	-					
$LiLa_9(SiO_4)_6O_2$	Pr	1, 5								
$LiLa_9(SiO_4)_6O_2$	Nd	1, 5								
Hafnates Tantalates										
$BaHfO_3$	Pr	1		fd(-)						
$BaHfO_3$	Ce	1								
$SrHfO_3$	Pr	1	10-300				200			
$SrHfO_3$	Ce	1	10-300				200			
Y_3TaO_7							240			
Borates										
YBO_3	Nd	1	10-300	fd(-) ff(+)			~160			
$LuBO_3$	Nd	1	10-300	fd(-) ff(+)			~160			
$ScBO_3$	Nd	1	10-300	fd(-) ff(+)			~160			
YBO_3	Pr	1	300	fd(+)	260		~160			15
$LuBO_3$	Pr	1	300	fd(+)	255		~160			13
$LuAl_3(BO_3)_4$	Nd	1	10-300	fd(-)						

Table 2: Luminescence properties of Ce, Pr and Nd in a variety of host lattices

In the project, we tried to produce transparent ceramics of YAG:Pr, LuAG:Pr and $LuPO_4$:Pr using a variety of methods. Though $LuPO_4$:Pr is not cubic, it has been studied in view of reports that it could be transformed into transparent ceramics. We could, however, not verify this.

Figures 1 shows the transparent YAG:Pr and LuAGe:Pr ceramics obtained.

Figure 1a: Transparent ceramics of YAG:Pr with different diameter and thickness (left: ∅ 3.2 cm, h: 2 mm; right: ∅ 2 cm, h: 9 mm)

Figure 1b. Transparent LuAG:Pr as prepared in the project (∅ 3.2 cm, h: 2 mm)

LuAG:Pr was chosen as material for further optimization and was prepared as ceramic material in Forschungszentrum Jülich (Germany). Its spectral characteristics are given in figure 2.

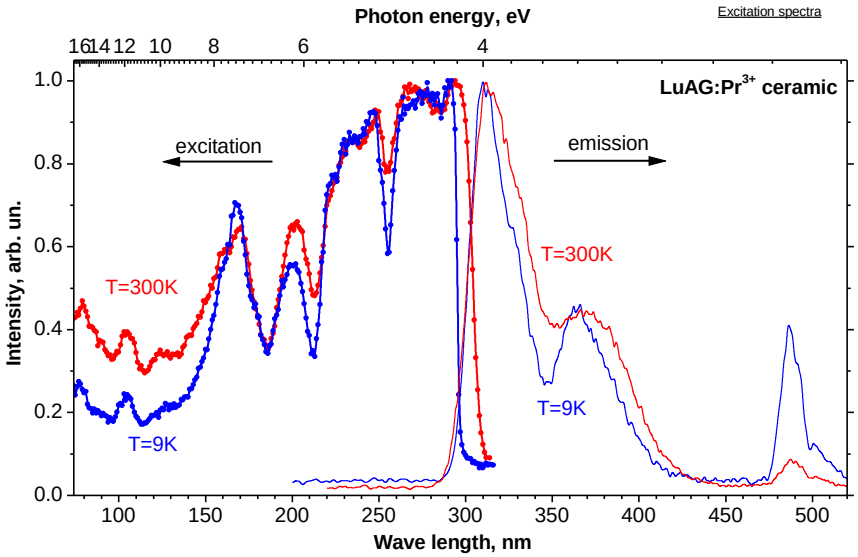


Figure 2. Excitation and emission spectra of LuAG:Pr ceramics at 9 K (blue) and 300 K (red)

LuAG:Pr^{3+} shows some afterglow. It has been shown that partial substitution of Al by Ga results in a decrease in afterglow, see figure 3. Too high Ga concentration results in considerable ff emission, which is slow and therefore undesired.

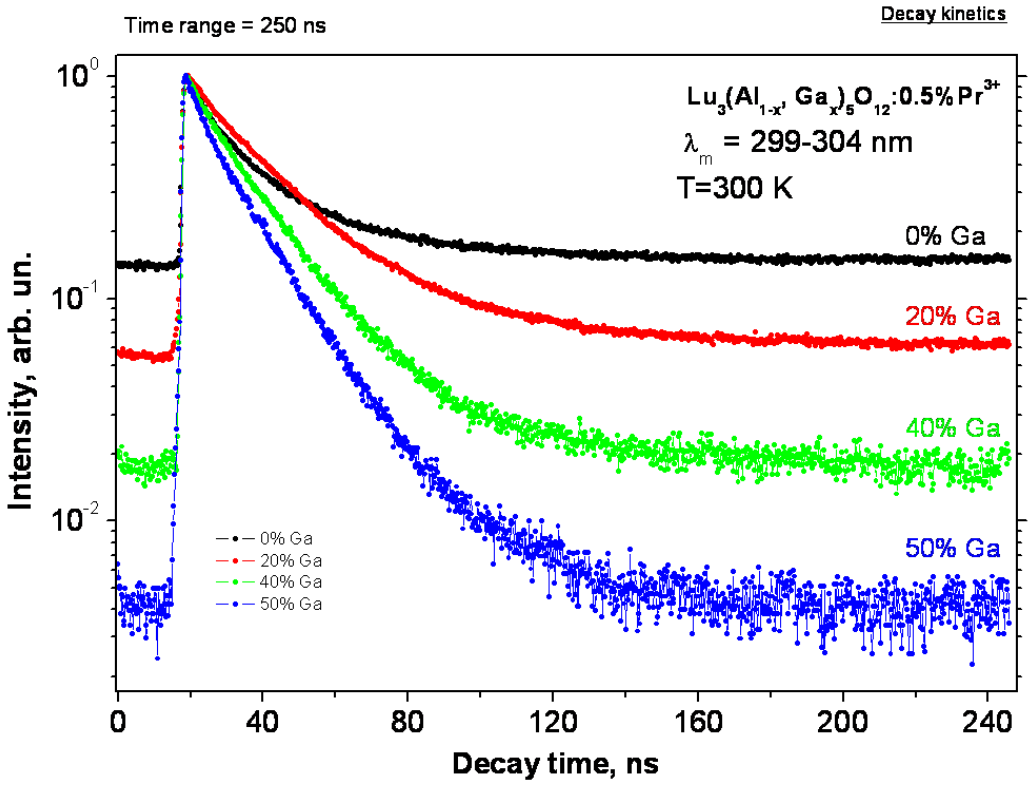


Figure 3. Emission decay of LuAG at 300 K with partial substitution of Al by Ga

Unfortunately, light yield measurements under γ-radiation resulted in very low light yields (less than 10000 photons/MeV) and a considerable fraction of 4f-4f emission (measured at TU Delft), see further below.

The ceramic scintillators obtained show emission in the UV. This is not compatible with the photodetectors used. Therefore, we have also investigated the possibility to obtain ultrafast wavelength converters (otherwise we will face timing issues with PET). The search was guided by quantum mechanical calculations. The quantum chemical calculations to identify wavelength shifters with strong absorption and a short decay time have resulted in a few design rules (WP4):

The work has resulted in few design rules:

1. The larger the conjugated aromatic molecule, the larger the transition dipole moment
2. Changing the molecule size can modify the transition energies. Larger molecules show transitions at lower energies
3. Linear conjugated aromatic molecules have larger transition moments than non-linear conjugated aromatic molecules
4. Withdrawing charge from the aromatic rings decreases the oscillator strength
5. The molecules should have a high symmetry

This result implies that the stilbenes and diphenyl acetylenes are very suitable for our purposes. If the oscillator strengths encountered are too small (too small a decay time), charge pushing groups might further reduce the emission decay time, without too largely affecting the transition energies.

Several new modified materials belonging to the classes of dihenyl acetylene and benzoxazole emitters have been designed, synthesized and characterized for their photophysical properties in solution and when embedded in solid state thin films. In general terms, most of the luminescent material studied shows a neat quantum yield increase with respect to solution when the luminophore is blocked in a rigid environment. Notably, a new symmetric bis benzoxazole shows a unit photoluminescence quantum yield in the solid state coupled to a short lifetime of the excited state (< 0.7 ns), with a good spectral match between the wavelength shifter absorption and the LuAG:Pr scintillator emission.

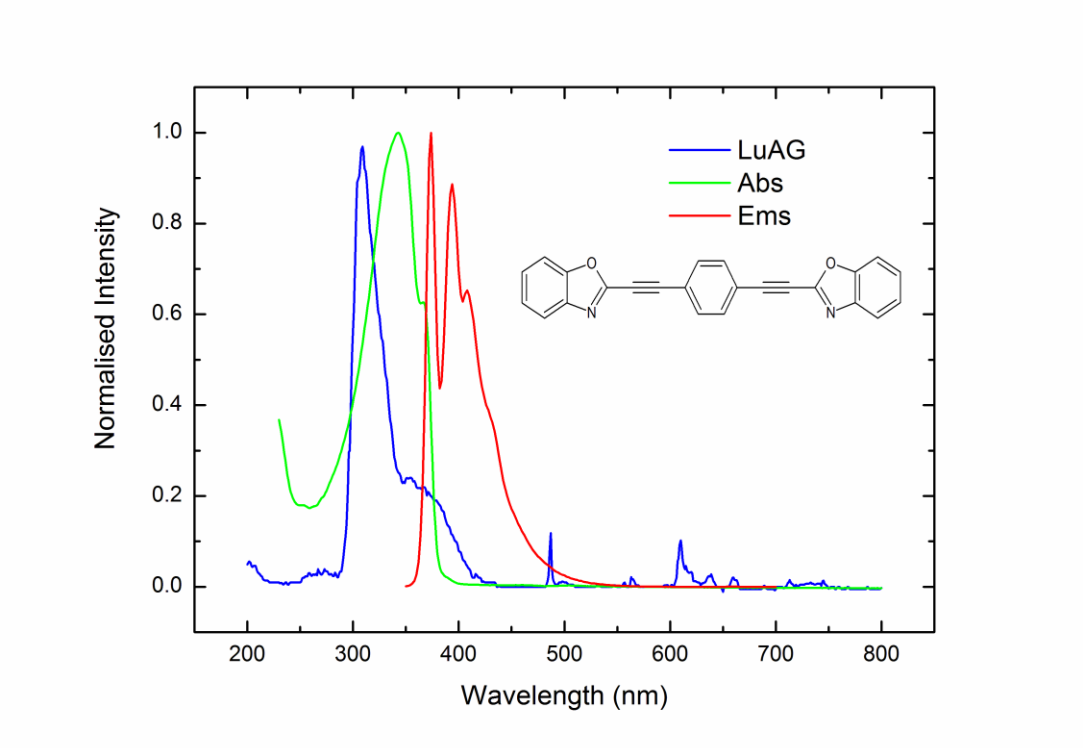


Figure 4 : Comparison of normalized intensity with wavelength.

Another part of this WP dealt with the preparation of suitable carriers to host the wavelength shifters. Carriers consisting of plastic and synthetic glass were used.

To use the deep UV photons as efficiently as possible, interference filters were designed and prepared. Both long wave- and short-wave pass filters were prepared. The transmission characteristics were optimized to the scintillator material chosen (LuAG:Pr). The filters consist of alternating Nb_2O_5/SiO_2 layers. Examples of the filters are given in the figure below.

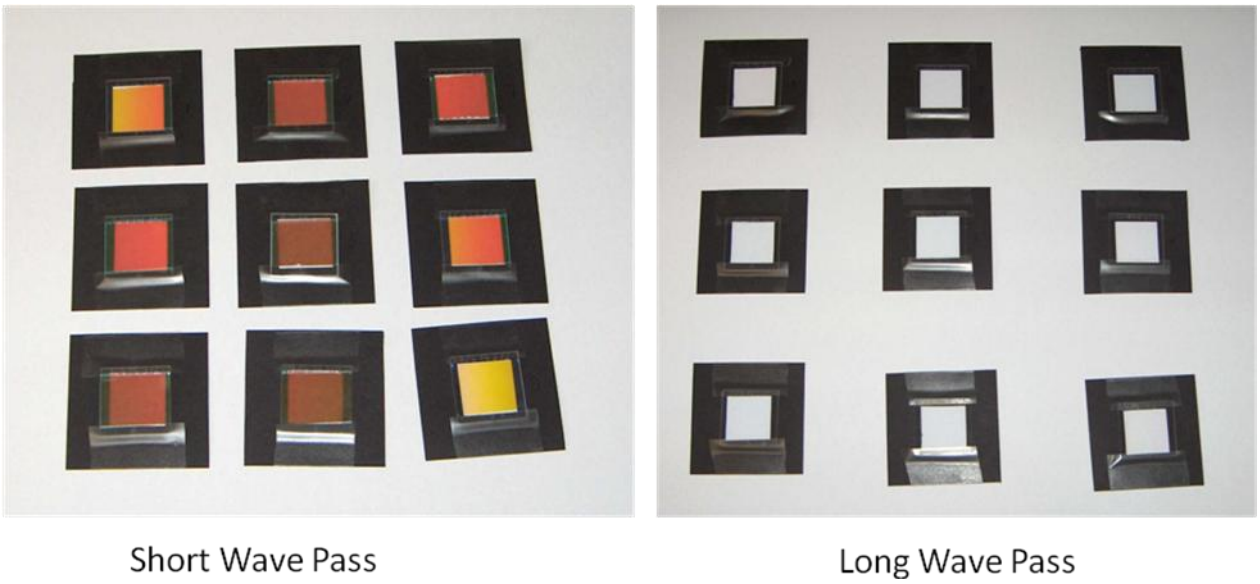


Figure 5. Examples of interference filters produced in WP5.

The characterization results of the ceramic scintillators YAG:Pr, LuAG:Pr and of single crystalline LuAG:Pr are reproduced in table 3. The table also contains measurements showing the effect of wavelength shifters and the combination of wavelength shifters and interference filters

Table 3. Light yield and energy resolution of YAG:Pr and LuAG:Pr ceramics, and of LuAG:Pr for single crystals. For the YAG:Pr ceramics, also the effect of the wavelength shifters and the interference filters have been determined (WP6)

YAG Sample, Cs source	shaping time (µs)	Yield [ph/MeV]	Energy resolution (%)
YAG	10	5303	not determined
YAG with NP03	10	4173	not determined
YAG with AB3	10	5819	7
YAG with DPO	10	4192	23
Complete stack: PMT-LWP375-AB3-Scint-SWP375	10	5467	8
YAG	0,5	3669	16
YAG with AB3	0,5	4174	13
YAG with DPO	0,5	2944	16
Complete stack: PMT-LWP375-AB3-Scint-SWP375	0,5	3016	20

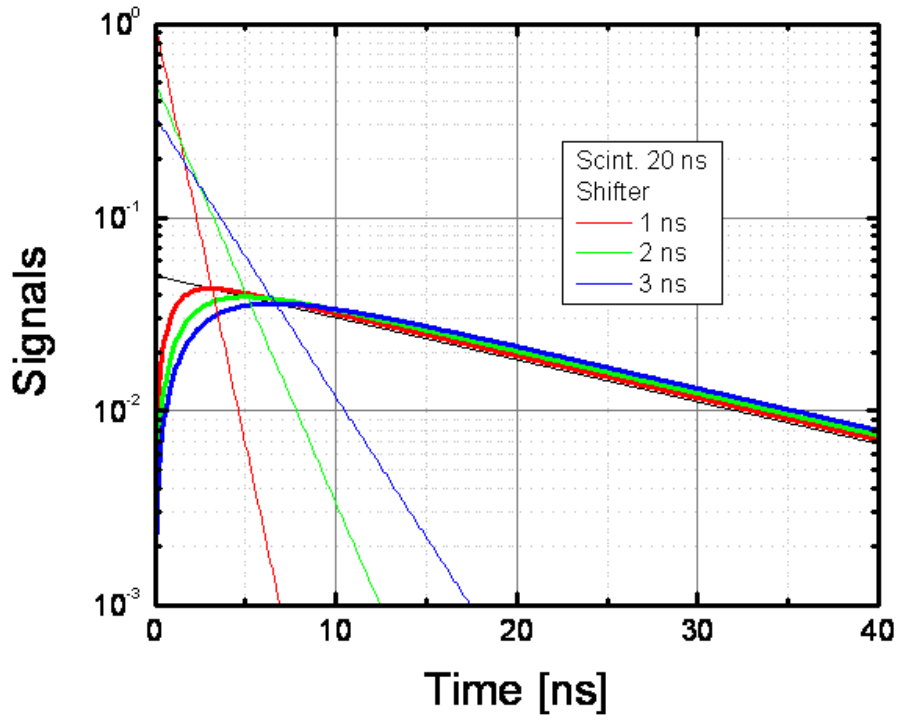
LuAG samples	Shaping time (µs), source	Yield (ph/MeV)	Energy resolution (%)
LuAG small single crystal	10, Cs	10554	7
	2, Cs	8228	7
	0,5, Cs	6030	9
	10, Am	10269	22
LuAG large single crystal	10, Cs	11816	13
	0,5, Cs	6757	11
	10, Am	11842	24
LuAG rod, single crystal	10, Cs	18764	4
	0,5, Cs	10534	5
	10, Am	18006	15
LuAG rod, single crystal (2)	10, Cs	18636	4
	0,5, Cs	10072	5
LuAG ceramic	10, Cs	6440	12
	0,5, Cs	4101	10

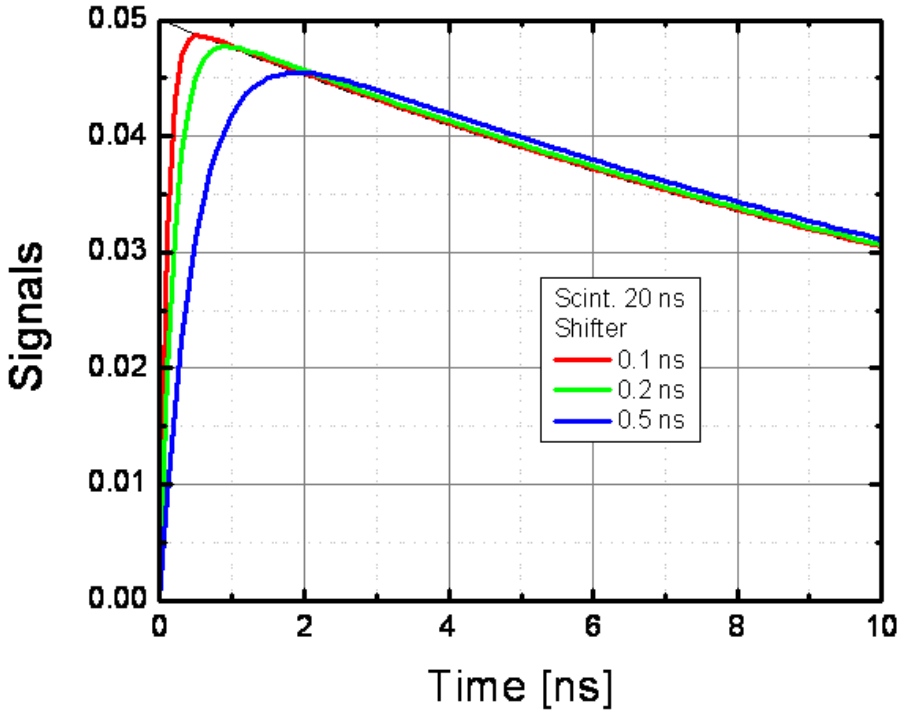
Table 3. Light yields and energy resolution of YAG:Pr and LuAG:Pr ceramics, and of LuAG:Pr for single crystals

3.4 Conclusions

1. The light yield of the best single crystalline LuAG:Pr material approaches 20000 photons/MeV.
2. The light yield of ceramic YAG is much lower, less than 6000 photons/MeV, which is far too low for PET applications and due to the rather low density of the material. Ceramic LuAG:Pr is only slightly better than ceramic YAG:Pr , although the density is higher (6.7 instead of 4.6 g/cm^3 for YAG). In this case the low light yield is probably due to the lower transparency of the specimens.
3. A significant fraction (30-40%) of the emitted light originates from slow 4f4f electronic transitions; this fraction is slightly smaller for YAG:Pr than for LuAG:Pr. As the spectral position of the 4f4f emission differs significantly from the fast 5d- 4f emission, the slow 4f-4f emission can be suppressed easily by the use of the interference filters. This fraction can be deduced approximately by comparing the light yield measured using the longest and the shortest gating times.
4. The number of photons per MeV emitted in the fast optical transitions that are suitable for PET applications for the best scintillators (single crystalline) characterized is about a factor of 2-3 too low for PET applications.
5. The energy resolution is, given the relatively low light yields, very good for both LuAG:Pr and YAG:Pr. Especially for the ceramic scintillators, this is a very significant result, as it shows that ceramic scintillators with a high energy resolution can be made. This is also reflected by the similar light yield of LuAG:Pr on excitation with Cs and Am (the photon energy of Am is about 10 times less than that of Cs).
6. YAG:Pr scintillators show a higher light yield when combined with wavelength shifter {AB3} (from WP4) than without a wavelength shifter. This must be due to slight inaccuracies in the calibration of the photomultiplier: the measuring system is designed to counts photons, independent of their wavelength.
7. The STRING stack (with YAG:Pr) shows a slightly reduced light output, this is presumably mainly due to the suppression of the 4f-4f emission lines, as it mainly shows up in the measurements with the short gating time.
8. The STRING stack results in a slightly reduced energy resolution, which very likely is acceptable.
9. LuAG:Pr is a promising material for PET applications:
    a. Provided that its light yield can be increased. Tthis requires further study, beyond the STRING project, which Philips will perform
    b. The energy resolution is very high, given the rather low light yield

In view of the rather low light yield, we have omitted testing the STRING stack under PET like conditions.We also omitted the manufacturing of an industrial prototype. Instead we modeled the time-dependent emission signal of the complete stack, as a function of the decay time of the scintillator and the wavelength shifter. The results are given in figures 6.





Figures 6. Simulated time dependent emission signal of the -STRING stack as a function of the wavelength shifter ('shifter') and the scintillator (20 ns).

We observe that only in case of a wavelength shifter with a decay time of 0.2 ns or less, the decay is single exponential after 1 ns (a project aim). Such wavelength shifters, simultaneously having a high quantum efficiency, are not known.

A significant number of the project objectives have been met:

1. A large number of luminescent materials showing fast emission (ns decay time) have been prepared and characterized
2. Transparent ceramics of YAG:Pr and LuAG:Pr have been obtained
3. Design rules for wavelength shifters have been identified and new wavelength shifter compositions combining a high quantum efficiency and a very fast decay have been prepared and characterized
4. Wavelength shifters have been incorporated in polycarbonate and glass
5. Interference filters have been designed, fabricated and produced, with their optical characteristics adapted to the optical properties of LuAG:Pr
6. The ceramic scintillators showed a light output which is far too low for PET applications (less than about 6000 ph/MeV), however the energy resolution is very promising
7. We did not characterize the ceramic scintillator-wavelength shifter-interference filter STRING stack under PET-like conditions, nor did we produce industrial prototypes, given the performance which was lower than expected. Instead, we modeled the influence of wavelength shifter on the time-dependent intensity of the emission generated by the stack.
8. We also omitted the investigation of the stability of the wavelength shifter under deep UV excitation. The radiation stability is compound dependent, and no suitable compounds have been found.

4 Dissemination and use

The project results are beyond immediate applicability. For this reason, this chapter contains information about dissemination in the form of publications, conference lectures and seminars only.

4.1 Section 1 – Exploitable knowledge and its Use

The project leader has applied for a patent describing the STRING concept. In addition, he has published a book on luminescence, in which also scintillators are being discussed, beit not intimately related to this project. The project leader also plans to use results of the STRING project for teaching purposes at the universities where he is active. Patent application (Fast radiation detectors, 6585US1)

The project results are beyond immediate applicability. For this reason, this chapter contains more general information about obtained knowledge without concrete plans for exploitation.
Most partners have been active at conferences, lectures, seminars and workshop and detailed information about this is available in the section 2 (next chapter).

4.2 Section 2 – Dissemination of knowledge

Dissemination Activities

Planned/ actual Dates	Presentation Title/ Type	Type of audience	Countries addressed	Size of audience	Partner responsible/ involved
01/2006	Project Website	All public			PRL-A
13/02/2008	Synthesis, characterisation and optical spectroscopy of rare earth doped nanocrystalline TiO_2 and Nb_2O_5	Institute Seminar, Bologna (I)	Italy	30 people	Uni-Verona (UNVIR)
24-28/03/ 2008	UV and visible luminescence of Pr3+ doped oxides: new materials.	Materials Research Society Symposium Proceedings 1111-D08-07, F	All world		UNVIR, PRL-A, UU, UT
24-28/03/ 2008	Optical materials for medical applications: an overview of ultrafast emitting oxidic Pr3+ scintillating materials.	Materials Research Society Symposium Proceedings 1111-D08-01,	All world		PRL-A, UU, UNIVR
June 2008	“Faster flashes from novel scintillators”	SP-SSM 2008, Nantes, France	France		Uni Utrecht, Philips Aachen, Uni Tartu
June 2008	“VUV spectroscopy and daily life: from efficiënt light sources	Symposium for the retirement of Prof. Georg	Germany		Uni Utrecht, Philips Aachen, Uni

Planned/ actual Dates	Presentation Title/ Type	Type of audience	Countries addressed	Size of audience	Partner responsible/ involved
	to medical imaging"	Zimmerer, Hamburg, Germany			Tartu
05-07/06/ 2008	Push-pull dyes for medical imaging applications	National Congress of Photochemistry 2008, Bertinoro, FC (I). Researchers and students.	Italy, France	100 people	ISOF-CNR
11 Jul 2008	"Luminescent salt",	ICL'08, Lyon	France		Uni Utrecht,
11 Jul 2008	"Dynamics of electronic excitations in some cerium-doped silicates in XUV-VUV",	Abs. Int. Conf. of Luminescence (ICL 2008), Lyon, France 2008, p. 515 (poster).			Uni Utrecht, Philips Aachen, Uni Tartu
13-16/11/2008	Spectroscopy of some Nd-doped phosphates	Abs. 15th Int. Conf. on Defects in Insulating Materials (ICDIM 2008), Aracaju, Brazil 2008, p. A118 (oral)			Uni Tartu, Uni Utrecht,
13-16/11/2008	Spectroscopy of LiLa9(SiO4)6O2 crystals doped with Pb and Bi"	Abs. 15th Int. Conf. on Defects in Insulating Materials (ICDIM 2008), Aracaju, Brazil 2008, p. A119 (poster).			Uni Utrecht, Uni Verona (UNVIR)
Dec. 2008	Optical Materials for Medical Applications: an Overview of Ultrafast Emitting Oxidic Pr^{3+} Scintillating Materials Invited talk Materials Research Society Meeting, Boston	Professors, students, industrial academics	USA	80	Philips Research Utrecht University University of Verona
Sept.06-Feb.10	Use of project results in educational lectures	Students and staff members	The Netherlands	10-15	PRL-A, UU
Jan. 2008, Juni 2009, Dec. 2009	Internal Seminars Philips Research	Philips employees	Germany Israel, The	20- 80	Philips

Planned/ actual Dates	Presentation Title/ Type	Type of audience	Countries addressed	Size of audience	Partner responsible/ involved
			Netherlands		
18/09/2009	Publication in ACS peer-reviewed journal. "Photophysical properties of tolan wavelength shifters in solution and embedded in polymeric organic thin films" J. Phys. Chem. C 2009, 113, 17927-17935.	Readers of international scientific journals.	All world	-	ISOF-CNR
09/ 2009	Visible luminescence of lanthanide ions in $Ca_3Sc_2Si_3O_{12}$ and $Ca_3Y_2Si_3O_{12}$	Journal of rare earths, Vol. 27, No. 4, , p. 555	All world		UNIVR
2009	Optical Materials for Medical Applications: an Overview of Ultrafast Emitting Oxidic Pr^{3+} Scintillating Materials	Materials Research Society Symposium Proceedings, Volume 1111, 2009	All world		PTL-A, UU and UNIVR
02/11/2009	Herstellung und Charakterisierung transparenter PET-Szintillatoren / Institute seminar FZJ – IEF-1	FZJ employees	Germany	40-50	FZJ
12/2009	Luminescence loss mechanisms	Journal of Luminescence, Volume 129, Issue 12, December 2009, Pages 1824-1826	All world		PRL-A
February 2010	Invited lecture University of applied Sciences Münster (Germany)	Professors, Students	Germany	30	Philips
2010	Publication in RSC peer-reviewed journal	Readers of international scientific journals.	All world	-	ISOF-CNR
05/05/2010	Optical spectroscopy	Journal of	All world		PRL-A , UU,

Planned/ actual Dates	Presentation Title/ Type	Type of audience	Countries addressed	Size of audience	Partner responsible/ involved
	of $Ca_3Sc_2Si_3O_{12}$, $Ca_3Y_2Si_3O_{12}$ and $Ca_3Lu_2Si_3O_{12}$ doped with Pr^{3+}	Luminescence Vol. 130, No. p. 893			UNIVR

4.3 Section 3 - Publishable results

No information available as follow-up studies will be defined, else see section 2 above.