High capacity SuperRENS-ROM disc with InSb active layer

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ABSTRACT

InSb material appears to be a serious candidate for an application to ROM discs for the next generation beyond Blu-ray. Its high potential for the super resolution effect seems to give a new impulse to this very attractive technology which guarantees the compatibility with the already existing Blu-ray players.

Key words: SuperRENS, Super resolution, InSb, ROM discs, $Zr0_2$, microstructure.

1. INTRODUCTION

Recent advances in multimedia applications and the internet require faster and denser memories. One of the most promising approaches is the use of the crystal-to-amorphous transition or phase change recording. This technology has realized optical disc memories such as DVD, Blu-ray, and HD DVD, and recently, it is rapidly expanding to the field of solid state non-volatile electric memory.

Today the phase change alloys are also at the heart of a future generation of optical discs post Blu-ray, the so-called super-resolution near-field structure (SuperRENS) discs [1-4] developed under the impulsion of Pr. Tominaga at the beginning of 2000s.

We propose in this paper to make a review on the development led at Léti on SuperRENS ROM discs based on InSb thin films. We will report the characteristics of our 53 GB ROM discs on the basis of bER evaluation including margins (readout power, tilt), readout and ageing stability.
Our SuperRENS ROM discs include ZrO_2 interface layers which improve drastically the stability of the media during the readout process. In a more fundamental approach, we will discuss the influence of these interfaces by analyzing the microstructure of the InSb active layer by XRD experiments at ESRF and TEM observations.

Finally, to go further in this promising way, we will show our last results obtained in the realization of a semi-transparent 53 GB superRENS ROM level and the 76 GB potential capacity of a hybrid dual level.

2. EXPERIMENTS

Figure 1 shows the 5-layer structure of our media. The substrate has a random pit pattern with 2T mark length of 80 nm. The track pitch is 280 nm. The capacity is 53 GB on a 120 mm diameter disc.
The dynamical tests were performed at CEA-Léti with BD optical pick up (λ=405 nm, NA=0.85, v_l=2.65m/s) and the bER evaluation was made by Thomson with the PRML detection method.

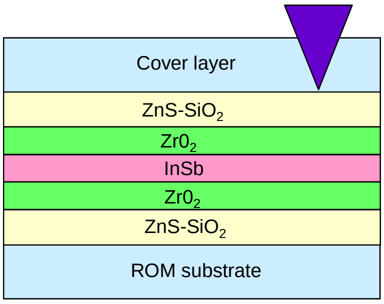

Figure 1: Disc structure

3. RESULTS & DISCUSSION

3.1 Performances of the 53 GB SuperRENS-ROM discs:

Figure 2 shows the readout power dependence of bER. The red line indicates a bER value of 3.0E-4 which is the threshold value for practical use. Readout power margin with bER less than 3.0E-4 is about 0.7 mW from 1.6 to 2.3 mW. Tangential and radial tilt measurements indicate a margin of around 2 degrees with a bER less than 3.0E-4. Our sample, submitted to an ageing test of 96 hours at 85°C with 80% humidity, shows a very good stability as shown in figure 2. The best bER after ageing is identical to the one before the test and the readout power margin is again close to 0.7 mW.
Figure 3 shows a result of readout stability at the readout power of 1.8 mW. This value allows getting good bER and the bER is kept under the threshold value till 40000 readout cycles thanks to the interface layers.

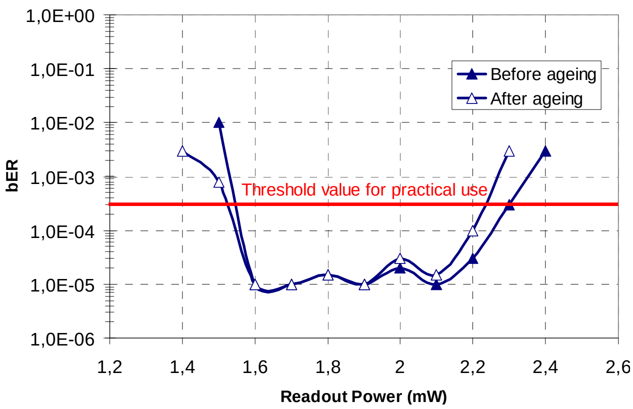

Figure 2: Readout power margin of bER
(53 GB SuperRENS ROM disc)

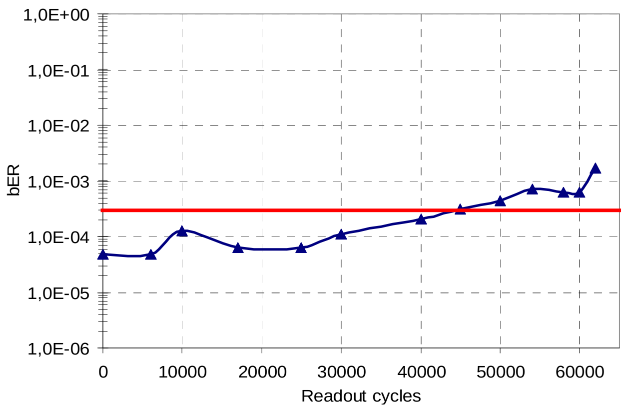

Figure 13: Readout stability (53 GB)

3.2 Discussion about the role of the interfaces of ZrO_2:

3.2.1 Microstructural analysis of the 5-layer structure:

The mechanism of super-resolution in InSb-based optical discs is complex and not yet completely understood. The present understanding is that InSb is an optically non-linear material the reflectivity of which is significantly increased upon exposure to intense light that generates a high concentration of non-equilibrium charge carriers [5]. So, under these assumptions the super-resolution effect depends strongly of the diffusion area of the electrons. The crystalline microstructure of the InSb layer seems to be a very crucial parameter since the electronic mobility value can be modified by the grains size and the grains boundaries.

The goal of our XRD studies made at ESRF (BM32 line) was to investigate the crystal size of InSb layers along different directions in order to see how photoexcited carriers may be confined wit respect to the readout bits. The idea of the experiment was to perform x-ray diffraction measurement on a device structure in different directions and to derive from these data information about special extent of the crystalline grains along the track and perpendicular to the track. Data were collected on a 5-layer disc which has undergone 16 readout cycles at the optimal power to get super-resolution effect (the InSb layer thickness is 20 nm).

The diffraction peaks of InSb (111, 220 and 311) were collected in the longitudinal direction (along the laser track in the disc plane), in the direction radial (perpendicular to the track in the disc plane) and in the direction perpendicular to the disc plane. Figure 4 shows a schematic representation of the analyzed three directions. Figure 5 shows the x-ray diffraction patterns acquired for these various orientations and Table 1 summarizes the calculated average crystallites size from Scherrer law. The following values have been obtained: 19 nm in height, 30 nm radially and 26 nm longitudinally.

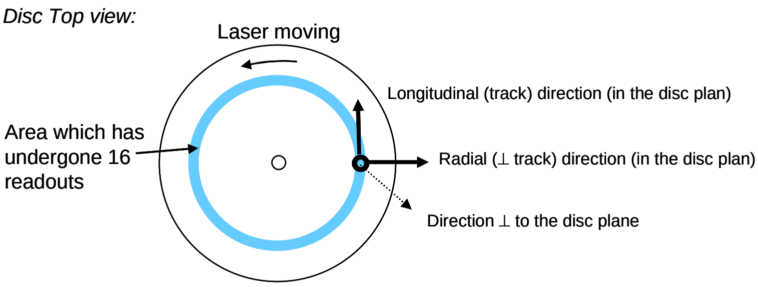

Figure 3: Schematic representation of the analyzed directions.

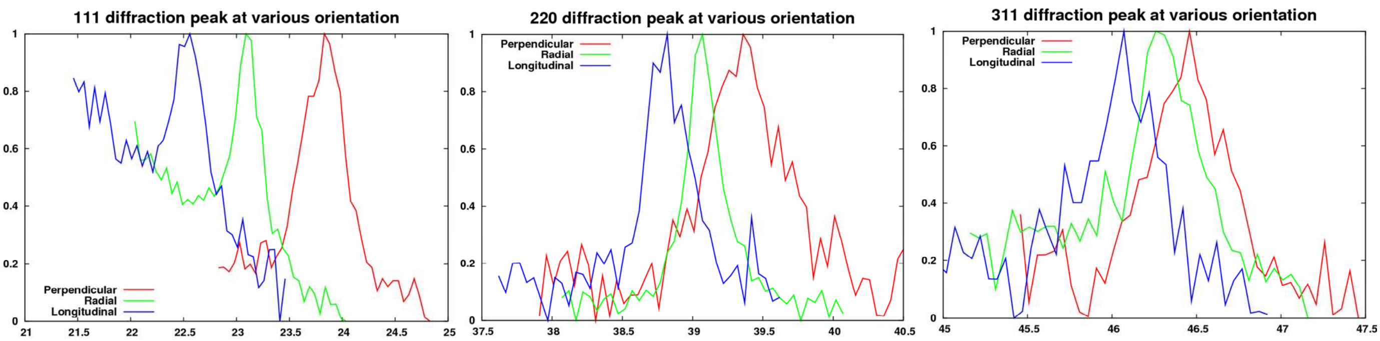

Figure 4: InSb diffraction peaks (111, 220, 311) collected at various orientations.

	(111) orientation	(220) orientation	(311) orientation
Average crystallites height	18.5 nm	16.6 nm	22.8 nm
Average radial size	29.4 nm	34.2 nm	27.3 nm
Average longitudinal size	25.9 nm	28.8 nm	22.4 nm

Table 1: Average grain sizes of the InSb crystallites according to Scherrer law (5-layer structure).

After 16 readout cycles, the height of the InSb grains corresponds to the thickness of the layer (~20 nm), the crystal growth is limited in this direction by the neighbouring layers. In the plane of the disc, the grains are free to expand and reach a size of 26/30 nm. This growth is however not so significant, the grains remain small in all the directions (whatever the crystal orientation), less than the size of the readout bit which is 80 nm. Many grains can cover the readout bit.

Complementary TEM observations were made on the same sample. Figure 5 shows clearly the 5-layer structure. A HR observation (Figure 7) focused on the darkest (InSb) layer shows the presence of grains of 20-25 nm in the longitudinal direction (coherent results with previous XRD experiments). Our observations of the InSb layer in the radial direction (Figure 8) indicate that the layer is polycrystallized (FFT exhibits bright points) but it is difficult to get information about the grains size.

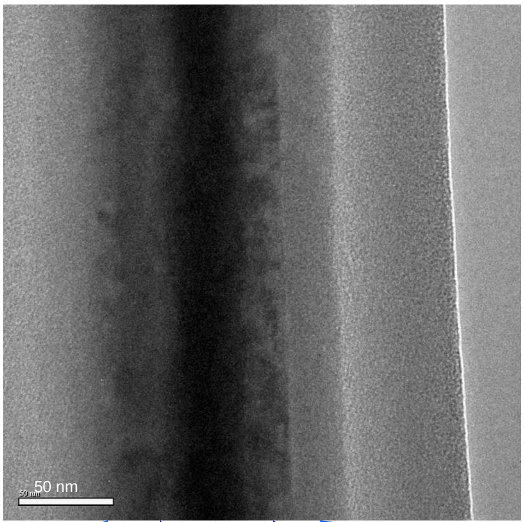

Figure 5: TEM observation of the 5-layer structure.

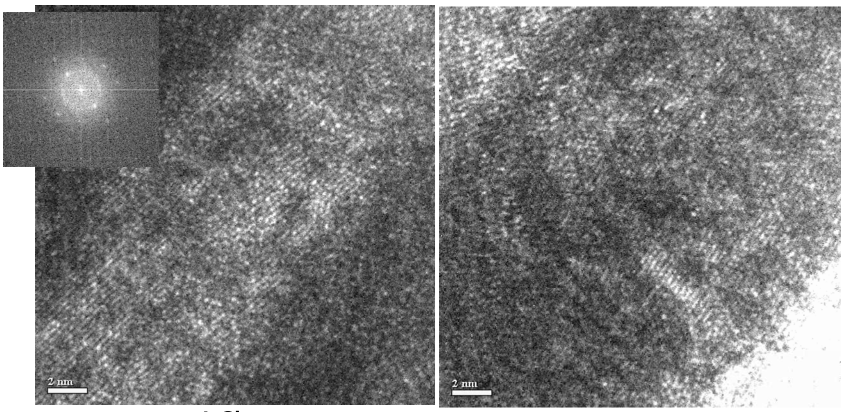

Figure 7: Longitudinal XS of the 5-layer structure (focus on InSb layer)

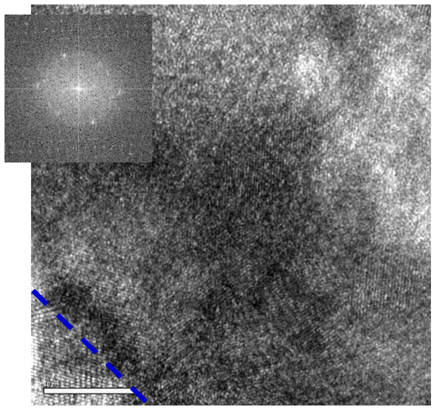

Figure 8: Radial XS (focus on InSb layer)

TEM observations, however, allow us getting a finer examination of the stack layers and especially ZrO_2 and ZnS-SiO_2 materials (Figure 9). The microstructure of the second dielectric is well known, it is made of very small crystallites (1-2 nm) of ZnS embedded in a SiO_2 matrix (figure 9, right image). ZrO_2 is a bit less known. Our observations indicate that the layer is polycrystalline with “big” grains of 15 nm crossing the layer.

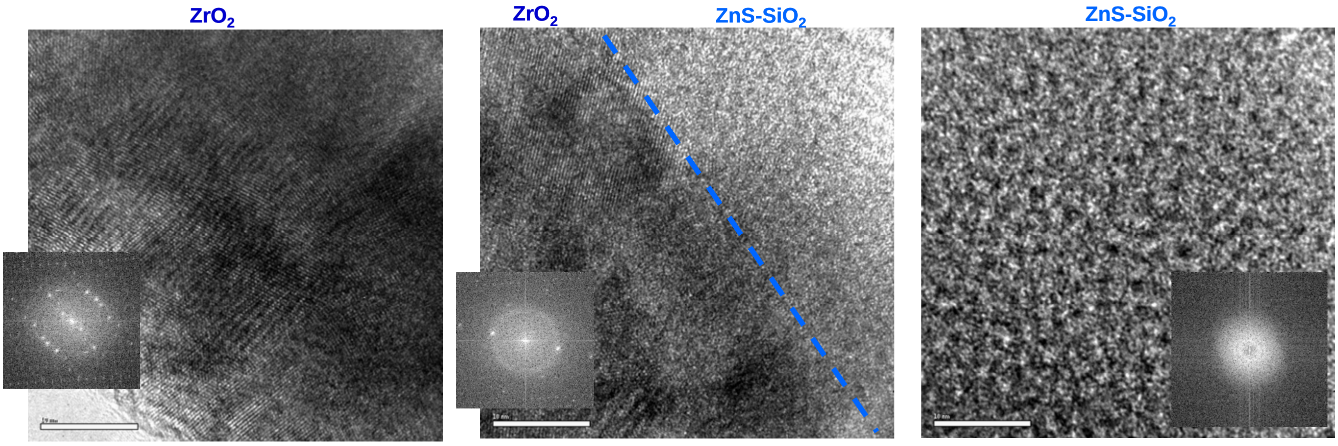

Figure 9: HR observations of the $ZnS\text{-}SiO_2$ and ZrO_2 layers

In order to give a view as complete as possible, we have made the same microstructure characterisations on a 3-layer structure (without ZrO_2 layers) which exhibits relatively poor stability versus readout cycles (a few thousands of readout cycles).

3.2.2 Microstructural analysis of the 3-layer structure:

X-ray diffraction measurements seem to indicate that, in the 3-layer stack, InSb grains are allowed to expand more in the disc plane than in the 5-layer structure. The collected data indicate that the average grains size is dependent of the InSb crystals orientation (Table 2). The (220) and (311) orientations seems favourable to the crystal growth and the average radial size of the grains after only 16 readout cycles reaches about 60 nm which means that the grains are anisotropic with a shape ratio of 3 between their height and their lateral size. One can note that the grains size is, here, close to the readout bit.

	(111) orientation	(220) orientation	(311) orientation
Average crystallites height	20 nm	-	-
Average radial size	33.8 nm	63.8 nm	59.3 nm

Table 2: Average grain sizes of the InSb crystallites according to Scherrer law (3-layer structure).

A planar TEM observation of this sample seems to confirm this behaviour (figure 10). Two grains orientations are clearly visible with a size of at least 30 nm (the real grain size measurement is limited by the dimension of the image).

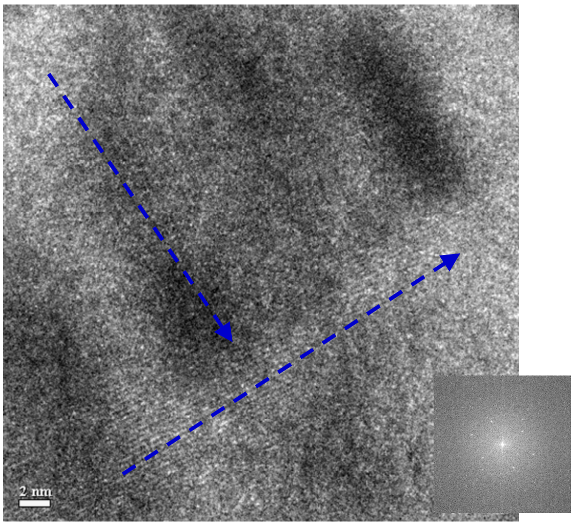

Figure 10: Top view (in the disc plane) of the InSb microstructure in the case of the 3-layer structure.

3.2.3 Summary:

To make a summary, we have observed after 16 readout cycles that in the case of the 5-layer structure, InSb grains size remains small, 25-30 nm whereas in the case of the 3-layer structure, the InSb grains have a dimension close to the readout bits (Figure 11). So, in the hypothesis of our electronic model, we think that the fine microstructure which is preserved in the 5-layer structure allows confining the photoelectrons, limiting their spatial extension and ensuring a small transition area with increased reflectivity and consequently an efficient superRENS effect.

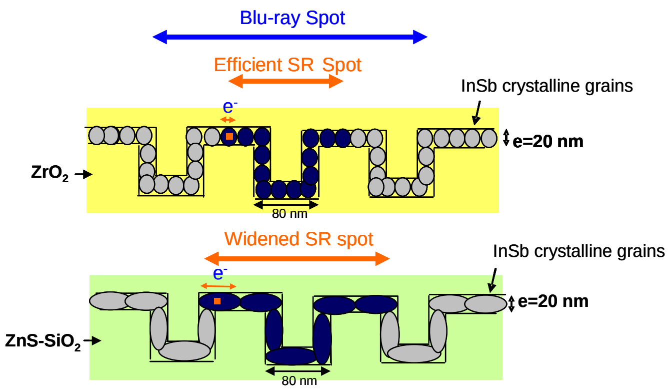

Figure 11: Schematic representation of the InSb microstructure when the adjacent dielectrics are ZrO_2 (top image) and ZnS-SiO_2 (bottom image)

The difference in behaviour between the two structures may be also an argument to explain the poor stability of the 3-layer structure compared to the 5-layer stack. One can think that after a sufficient number of readout cycles, the size of the InSb grains in the 3-layer structure becomes larger than the readout bits reducing consequently the efficiency of the SuperRENS effect.

At the same time, exposure to intense laser can heat the material and allow the diffusion of undesirable elements within the InSb material, degrading progressively the quality the material and its properties. Both high thermal stability of ZrO_2 material and its specific microstructure with "big" grains prevent more efficiently from the chemical diffusion than the less stable nanostructure of the ZnS-SiO_2 composite material.

3.3 53 GB semi-transparent SuperRENS-ROM disc

The structure of these discs is the same as in the previous case (see figure 1). The only change is the InSb thickness which was decreased. The optical properties of the media were measured as follows: Reflectivity R_{8H}=18%, Transmission $T_{InSb\ crystal}$=40%. These characteristics are compatible with the specifications of the upper level of a dual-level ROM disc. Figure 12 shows the readout power dependence of bER. In comparison to the non semi-transparent disc described in paragraph 3.1, one can note an increase of 0.3 mW of the readout power to obtain good bER, namely 1.85 mW (instead of 1.55 mW). The readout power margin seems to be very good, higher than 0.7 mW (above 2.5 mW, we are limited by the performances of our optical pick up). The readout stability is again comfortable (figure 13); about 40000 cycles can be measured with a bER less than the threshold value of 3.0E-4.

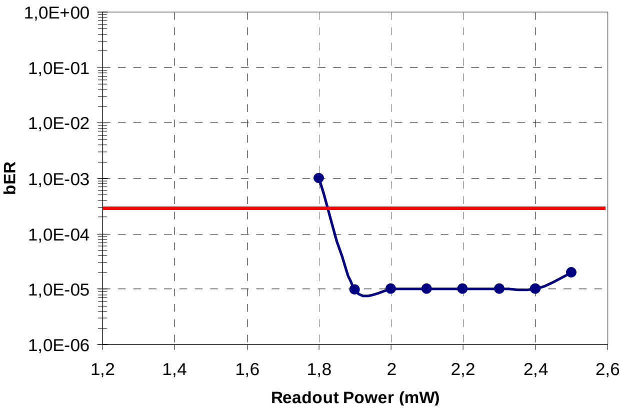

Figure 12: Readout power margin of bER
(53 GB semi-transparent SuperRENS ROM disc)

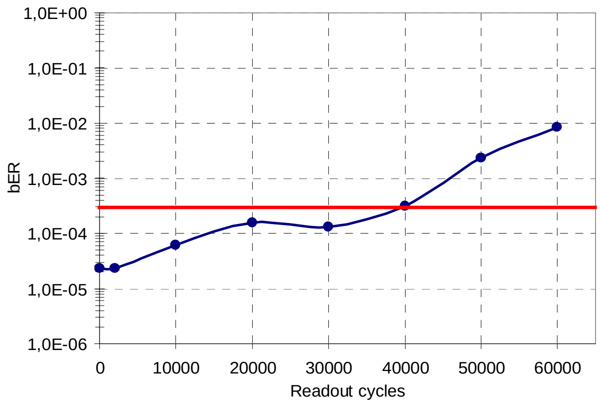

Figure 13: Readout stability

3.4 Toward 76 GB hybrid (Blu-ray/SuperRENS ROM) dual level disc

The optical and bER characteristics measured on the discs described in paragraph 3.3 allows considering the realization of a dual level medium with a classical 23 GB Blu-ray ROM for the buried level and a 53 GB superRENS ROM for the semi-transparent level. Table 3 summarizes the main characteristics of this virtual 76 GB dual level system; as we write this abstract, the measurements were made on separate levels.

Level	L1 53 GB (1/2 transparent level)	L0 23 GB (buried level)	23 GB Blu-ray ROM Spec.
λ	405 nm		405 nm
NA	0.85		0.85
Track pitch	280 nm	320 nm	320 nm
Channel bit length	40 nm	80 nm	80 nm
Readout power	1.9 mW	0.4 mW	0.3 mW
Limit EQ jitter	-	6.5 %	= 6.5%
beR	10^{-5}	-	= 3.10^{-4}
R_{8H}	18%	12% (through L1)	12%<R_{8H}<28%
Cyclability	40 000	-	-

Table 3: Summary of the performances measured on each level

4. CONCLUSION

4.1 Conclusion about the mechanism of super-resolution and further studies

In our present model, the working hypothesis is that the irradiated InSb layer generates a high concentration of photoexcited carriers which modify locally the optical properties of the layer from a semiconductive state to a metallic one inducing a reflectivity increase. Under this assumption, we have highlighted in this paper, the strong influence of the crystalline microstructure (grains size) of the InSb film in the efficiency of the super-resolution process and the role of the adjacent layers in the definition of this microstructure. However, it is clear that due to the relaxation of free carriers by collision with the lattice the temperature of the sample also increases. Important questions whether or not the irradiated InSb is molten in the disc structure as well as whether the reflectivity change is a purely optical effect remain unknown. In order to investigate the kinetics of the light-induced changes in InSb we intend to apply for beamtime at Spring-8 to perform time-resolved XAFS experiments.

4.2 Conclusion about the next technological steps

We evaluated the main characteristics of 53 GB SuperRENS ROM discs and we showed the performances measured on separate levels of a potentially 76 GB dual level structure including a semi-transparent 53 GB SuperRENS ROM level and a classical Blu-ray ROM buried level.
The results show a good potential of the InSb-based structure both for single level discs and for dual level media. The next challenging step is now to propose a 100 GB dual level disc with two SuperRENS levels.

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Biography

Bérangere Hyot received her PhD in materials science from INPG (Polytechnique National Institute of Grenoble) in 2001. Since joining CEA/LETI in 2002, she has been involved in data storage R&D research involving phase-change recording; write once recording and ultra-high density optical storage.