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Photosensitivity and directly UV written waveguides in an ion exchangeable bulk oxide glass.

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Abstract

In this paper we present the study of photosensitivity and the direct writing of a germanosilicate glass doped with boron, known as SGBN. We report the first example, to our knowledge, of directly UV written waveguides in a bulk multicomponent oxide glass exposed to a frequency doubled Ar ion laser.

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1. Introduction

Photosensitivity in glasses is a fundamental property exploited for their employment in device fabrication for the telecommunication industry. Glasses showing high photosensitivity, like germanosilicate glasses, can be used either for grating fabrication or for direct UV writing of waveguides. While the first application finds its higher development in the fiber based devices,

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the second is fast developing into a very interesting and promising technique for planar waveguides production.

There are different methods for producing channel waveguides in silica based glasses: for example, the Ion Exchange technique [1], the Chemical Vapor Deposition techniques (as PECVD [2], FHD [3]) followed by the RIE (Reactive Ion Etching) and/or UV writing through a photolithographic mask [4], which is commercially developed, and by the direct UV writing of waveguides [5]. The advantage of direct UV writing is that there is no need to use photolithography, which involves high cost fabrication steps. In ref [5] direct UV written waveguides were produced using PECVD deposited layers. To date, there has been no reported literature on direct UV written channels on bulk multicomponent oxide glass using the photosensitive of germania. Recent laser results measured in waveguides fabricated by direct UV writing on Nd-doped fluoroaluminate glass has been reported [6]. The advantages in the use of bulk glasses are: the ease and low cost procedure of batching the melt, the customizable composition, the possibility of introducing large amounts of volatile components and active ions.

In this paper the employment of direct UV writing on highly photosensitive silicate based glass is shown, with the aim of obtaining guiding structures. A series of direct writing experiment was performed, which led to the realization, to our knowledge, of the first directly written positive channel waveguide in a bulk multicomponent glass. At the same time an investigation of the change of the UV spectrum due to a KrF excimer laser (λ=248nm) was performed in order to understand the possible defects involved in the process of the refractive index change under UV irradiation.

Two different kinds of glasses were used. The first is called SGBN from the initials of its main components: silica, germania, boron oxide and sodium oxide. Such glass was designed and produced at the Politecnico di Torino: Na_2O was originally introduced to allow the ion exchange process for waveguides fabrication [7] [8], GeO_2 and B_2O_3 were added for photosensitive purposes. A first measurement of the glass photosensitivity was performed on the "as cast glass", after exposure to a KrF excimer laser operating at 248nm: a refractive index change up to 10^{-2} was measured via the Brewster's angle method [9]. A following experiment was performed on the ion exchanged glass, by exposing one branch of an integrated Mach-Zehnder interferometer to a KrF excimer laser [9] and measuring in line the displacement of the correspondent interference curve due to the change in the refractive index: the result was a Δn equal to $1.5 \cdot 10^{-4}$. The glass was then demonstrated to be photosensitive, both as prepared and ion exchanged. The big refractive index change displayed on the compound glass led us to the conclusion that direct writing experiments could be performed on the same glass.

The second kind of glass employed was a commercial germanosilicate preform obtained by VAD (Vapor Axial Deposition). The series of exposures programmed aimed to reproduce the conditions of direct writing on a commercial germanosilicate glass, in order to compare the effect of the UV laser beam on the different glass compositions.

2. Experimental.

2.1 Glass synthesis

The SGBN glass samples were prepared by melting the batch powders in a Pt crucible in a furnace at a temperature of approximately 1600°C for 1h. The glasses were cast on a copper mould at room temperature, and then annealed. Two different samples with two different concentrations of Ge were prepared, called SGBN6 and SGBN20, containing 6%mol and 20%mol GeO_2 respectively in a way that the total amount of SiO_2 and GeO_2 were kept constant. SGBN6 and SGBN20 has T_g values of 536 and 532°C and a linear expansion coefficients of 88 and 101[$\cdot 10^{-7}$°C^{-1}], respectively.

The glass preform used for the experiment was a Pirelli VAD preform: it was made of a pure SiO_2 cladding (n=1.4585) and a GeO_2-SiO_2 core (n=1.4628). The numerical aperture was 0.11.

2.2 KrF laser exposures and UV spectra

The samples, after cutting and optical polishing down to~200 μm thickness, were mounted on an Al mask with aperture of 3mm diameter. The samples were, exposed to an increasing number of pulses of a KrF excimer laser working at 248nm with nominal conditions being ~100mJ/cm^2 at 10Hz. After every exposure the samples were scanned with a Perkin Elmer Lambda 19 UV spectrophotometer and the results displayed in a dB/cm vs. wavelength plots.

2.3 UV direct writing

The glass samples fabricated for the experiment were first cut, lapped and polished to an optical quality. The source used for direct UV writing was a CW frequency doubled Ar ion laser operating at λ = 244nm. The samples were positioned on a vacuum chuck connected to a computer controlled translation stage, which shifted perpendicularly to the incident UV laser beam at different speeds (illustrated in Fig. 1). Focusing of the laser beam on the sample was required before every experiment. The beam focus incident on the glass surface was 6μm.

After the exposure the samples were observed with an optical microscope in order to check the possible presence of visible effects of the UV beam on the glass.

Alpha step runs were then performed on the samples to verify the observations of the optical microscope and quantify the physical effects observed.

The guiding structures were characterized by launching light with a He-Ne laser: near field and far field images were produced, loss and NA measurements were performed.

3. Results and discussion

3.1 SGBN6

The response of SGBN6 glass to KrF laser irradiation is shown in Fig.2. Before exposure it showed an absorption near 250nm corresponding to the 5-eV band [10]. After each set of exposures, the absorption was remeasured. Following irradiation, an excess absorption was observed in the wavelength range sampled but with a lower increase of absorption in the wavelength region near 250nm as displayed in the inset. A bleaching of the peak occurs near 250nm. This bleaching is generally accompanied by an induced absorption near 190nm, the 6.3eV band, assigned to GeE' centers . We did not measure in the vacuum UV but deduce from our results that the conversion from GODC to GeE' centers occurred on 248nm irradiation. The formation of GeE' centers is responsible for the refractive index change in germanosilicate glasses .

The direct UV writing experiments were performed with laser beam powers ranging from 350mW to 100mW and scan rates from 3000 to 3mm/min. At higher powers a series of ablated channel were obtained on the glass surface, showing a central deep valley (0.9μm deep at 350mW, 3000mm/min) and 0.6μm side lobes. At lower powers, particularly at 150mW no ablation was evident and a series of vertical slab waveguides were produced in the glass, as shown in Fig.1. Tab.1 gives a summary of our observations. The waveguides written with 150mW power were directly written in the glass and they were vertical, and extending through the whole thickness of the glass (900μm). These were 6μm wide and a measurement of the refractive index change was not possible, due to their shape and position.

The formation of a slab waveguide indicate that there is sufficient power in the beam to penetrate a 2mm thick sample. This suggests the possibility of writing channels all the way through the glass, by a static exposure, which means without scanning the laser beam with respect to the sample. The aim was to write vertical channel waveguides linking two opposite sides of a sample to obtain some measure of the refractive index change. The series of exposures is shown in Tab.2.

The laser power (P) ranged from 200 mW to 100 mW, the exposures lasted for 1 second each and five different exposures were performed for each power condition. In some cases, particularly at higher powers, a surface damage occurred, since the laser power was oscillating.

As shown in the Tab.2, a series of channels, light guiding structures, were produced and the best performance obtained was: NA = 0.038, $\Delta n = 4.8 \cdot 10^{-4}$ and loss = 5.9 dB/cm at λ=633nm for the exposures at 200 mW. The refractive index change close to the surface (~10 µm into the glass for example), where the laser write beam is almost unattenuated, is expected to be much higher.

3.2 SGBN20

The response of SGBN20 glass to KrF laser irradiation is shown in Fig.3. The bulk glass before exposure shows a higher absorption coefficient at 248nm of 51dB/mm versus 4dB/mm for SGBN6. In this case, however, no peak was detected at 240nm (though a 100µm thick slide was used) because of the overall increase in absorption in the ultraviolet region. Following exposure, a change in absorption occurs, leading to an increase for low amounts of irradiation (until 100 pulses) and then to a decrease at higher amounts. As can be seen in the inset graph, a bleaching occurs around 240nm, corresponding to a decrease of GODC concentration.

The direct writing experiment performed on this glass were more critical than in the previous case: the high absorption of this glass to the UV laser beam made the focusing of the sample difficult.

Table 3 shows the writing schedule for such glass and the observation of the effect of the laser beam.

As previously observed in SGBN6 glass, there is the production, at high energies, of ablated channels on the sample surface and at low energy of vertical slab waveguides. In the latter case, however, slab waveguide did not occur along the entire thickness of the sample, (thickness = 2mm) because the high absorption of the glass at 244nm effectively attenuated the beam.

For the SGBN20 sample, we also observed photothermal expansion and called here as "surface relief": such effect corresponded to the formation of a bump all along the writing path. Such bump was first observed at the optical microscope, and then the alpha step scan in order to measure its dimensions. Fig.4 shows the surface profile of SGBN20, where there are two surface relieves (# 2 and 6) and an ablated channel (#3). The surface relieves labeled 2 and 6 are 0.6 and 0.4 [μm] high, respectively and both are 20 [μm] wide.

The second surface relief (#6), obtained at lower power and lower scan rate showed, when light was launched on an optical bench through it, the presence of an underlying channel waveguide. Its characteristics were: NA=0.05, corresponding to a Δn of 8·10-4; loss=8.2 [dB/cm]. The loss is mostly from the bulk material as shown in Fig.3. It was the first example, to our knowledge, of a channel waveguide directly written in a bulk multicomponent glass. Its schematic writing process and the corresponding near field image are displayed in Fig.5.

In order to understand the position of the waveguide with respect to the glass surface and the surface relief, a polishing of the surface of the sample was performed, until the surface relief was polished out. The result was the waveguide was still there after polishing. The process of UV writing had produced in this glass and at these particular UV writing conditions a buried waveguide and a core and cladding were written simultaneously.

An attempt to write static exposure channels were also performed as with SGBN6. The exposures gave the results summarized in Tab.4.

At low power condition, no effect was observed on the sample, neither a physical densification or expansion. At intermediate power values, channel waveguides were obtained, and the best performance in terms of optical properties of the waveguide was: NA = 0.06, $\Delta n = 1.2\cdot 10^{-3}$, for a 50mW and 1s exposure. A damage threshold of 100mW was then detected: as previously seen, SGBN20 has a higher absorption to UV light and a consequent lower threshold damage with respect to SGBN6.

3.3 Germanosilicate preform

The commercial VAD preform was first cut in half along the main axis and then polished on the surface. A direct UV experiment performed followed the schedule displayed in Tab.5.

After UV writing, launching light from a He Ne laser on an optical bench, a series of slab waveguides, like those detected for SGBN6, was visible. In this case, such slab waveguides, were present only in the core region (a series of direct writing experiments were performed also in the cladding region with no result). In addition, the slab waveguides occurred for higher laser powers. In particular, the brightest ones occurred at 300mW laser power.

A thermal treatment was then performed in order to test the erasure threshold. The sample was heated inside a furnace at 300°C for 1h, with a small decrease in brightness for waveguides written at 100mW, but with no significant change for the other ones. A second heat treatment at 300°C for 2h did not bring any change in the waveguide intensities. A further heat treatment at 500°C for 3h produced an erasure of almost all the waveguides, except one of the waveguides written at 300mW, which was very faint, but still visible. A first conclusion was that slab waveguides written on a germanosilicate core occurred at higher laser power and they had a higher relative refractive index than those written in an SGBN glass. Such effect was likely due to the absence of Na and B ions, which produce in the SGBN glass a decrease in the characteristic temperatures and a corresponding lower threshold damage of the material with respect to a sodium and boron free glass. Indeed at the exposure conditions at which in the preform bright slab waveguides were obtained, in the SGBN glass ablated channels were produced.

4. Conclusions

In this paper we showed that SGBN glasses are suitable for direct UV writing of waveguides. In the 6%GeO_2 glass we UV wrote vertical slab waveguides and vertical channel waveguides, without any physical modification of the surface of the sample. In the SGBN20, besides observing similar features as in SGBN6 (at lower laser powers, on the average), we produced the first, to our knowledge, directly written channel waveguide in a bulk multicomponent glass. There is still much to understand on the mechanism of realization of such waveguides, in particularly in the case of the light guided through the surface relief. The core/cladding structure of such device is promising for applications in the telecommunications.

Ablation is a limiting feature, and reduction of Na content can be considered in order to shift the damage threshold and obtain larger refractive index changes. We have shown, indeed, that in a sodium free germanosilicate glass, vertical slab waveguides occur at higher powers and such effect is shown here for the first time.

The presence of germanium oxide is necessary for the refractive index change and the UV absorption studies show the correlation between the refractive index changes and the loss change in the glass.

The results shown offer many possibilities for future developments of suitable glass compositions able to give the desired direct writing properties. The ablation effect suggest the possibility of efficient relief gratings (type II) on SGBN glasses. The realization of vertical slab waveguides and channel waveguides are open to new applications, like 2D and 3D UV writing inside the bulk glass and the simultaneous processing of waveguides and gratings.

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Figure Captions

1. (a) scheme showing the UV direct writing on the SGBN6 glass performed at 150mW and 3000mm/min; (b) image of the obtained slab waveguide (photograph).

2. UV absorption spectra of SGBN6 (~155μm thick slice) vs. KrF excimer laser exposures (20Hz repetition rate, Ip~150mJ/cm^2). Inset: UV induced absorption changes.

3. UV absorption spectra of SGBN20 (~155μm thick slice) vs. KrF excimer laser exposures (20Hz repetition rate, Ip~100mJ/cm^2). Inset: UV induced absorption changes.

4. Alpha step profile of SGBN20: channel 2 ,3 and 6 are labeled.

5. (a) scheme showing the UV direct writing on the SGBN20 glass performed at 100mW and 30mm/min; (b) image of the obtained channel waveguide (near field picture).

Table 1
Summary of 244nm CW direct writing on SGBN6 sample. Sample thickness is 900μm.

SGBN6		Laser power [mW] 150	350
Scan rate [mm/min]	3000	Vertical slab waveguide	Ablated channel
	300	Vertical slab waveguide	Ablated channel
	30	Vertical slab waveguide	Ablated channel

Table 2

Static exposures performed on SGBN6 sample. Sample thickness was 900μm

P [mW]	**t [sec]**	**Number of exposures**	**Observations**
200	1	5	2 channels
150	1	5	4 channels
100	1	5	5 channels

Table 3
Results of scanning direct UV writing exposures on SGBN20 sample . Sample thickness is 2mm.

SGBN20		**Laser power [mW]** **100**	**150**
Scan rate [mm/min]	**3000**	Vertical slab waveguide	Vertical slab waveguide
	300	Vertical slab waveguide	Surface relief
	30	Surface relief	Ablated channel

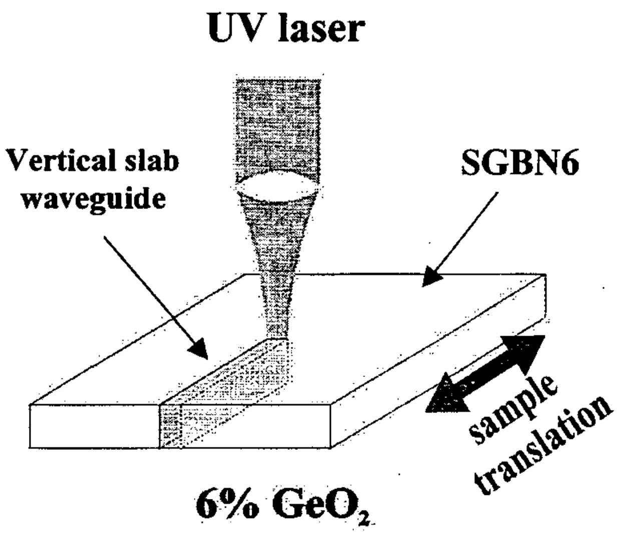
Table 4
Summary of static UV exposure on SGBN20 after 1 and 5 seconds of exposure time. Sample thickness is 100µm.

SGBN20 static exposure		Results
Laser power [mW]	100	Damage
	50	Channel waveguide
	20	Faint channel waveguide
	10	No effect

Table 5
Results of scanning direct UV writing exposures on preform. Sample thickness is 2mm.

Preform		**Laser power [mW]**	
		200	**300**
Scan rate [mm/min]	**30**	Vertical slab waveguide (faint)	Vertical slab waveguide
	15	Not performed	Vertical slab waveguide (intense)

Fig.1 – (a) scheme showing the UV direct writing on the SGBN6 glass performed at 150mW and 3000 mm/min; (b) image of the obtained slab waveguide (photograph).



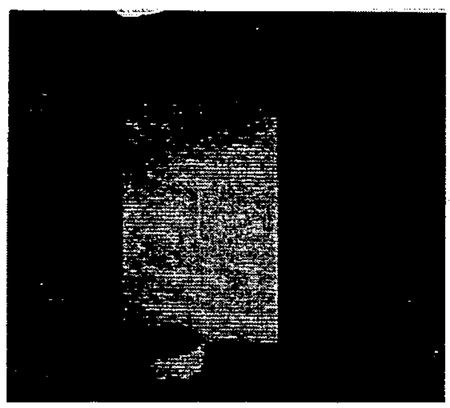


Fig. 2 – UV absorption spectra of SGBN6 (~155μm thick slice) vs. KrF excimer laser exposures (20Hz repetition rate, Ip~150mJ/cm[2]).

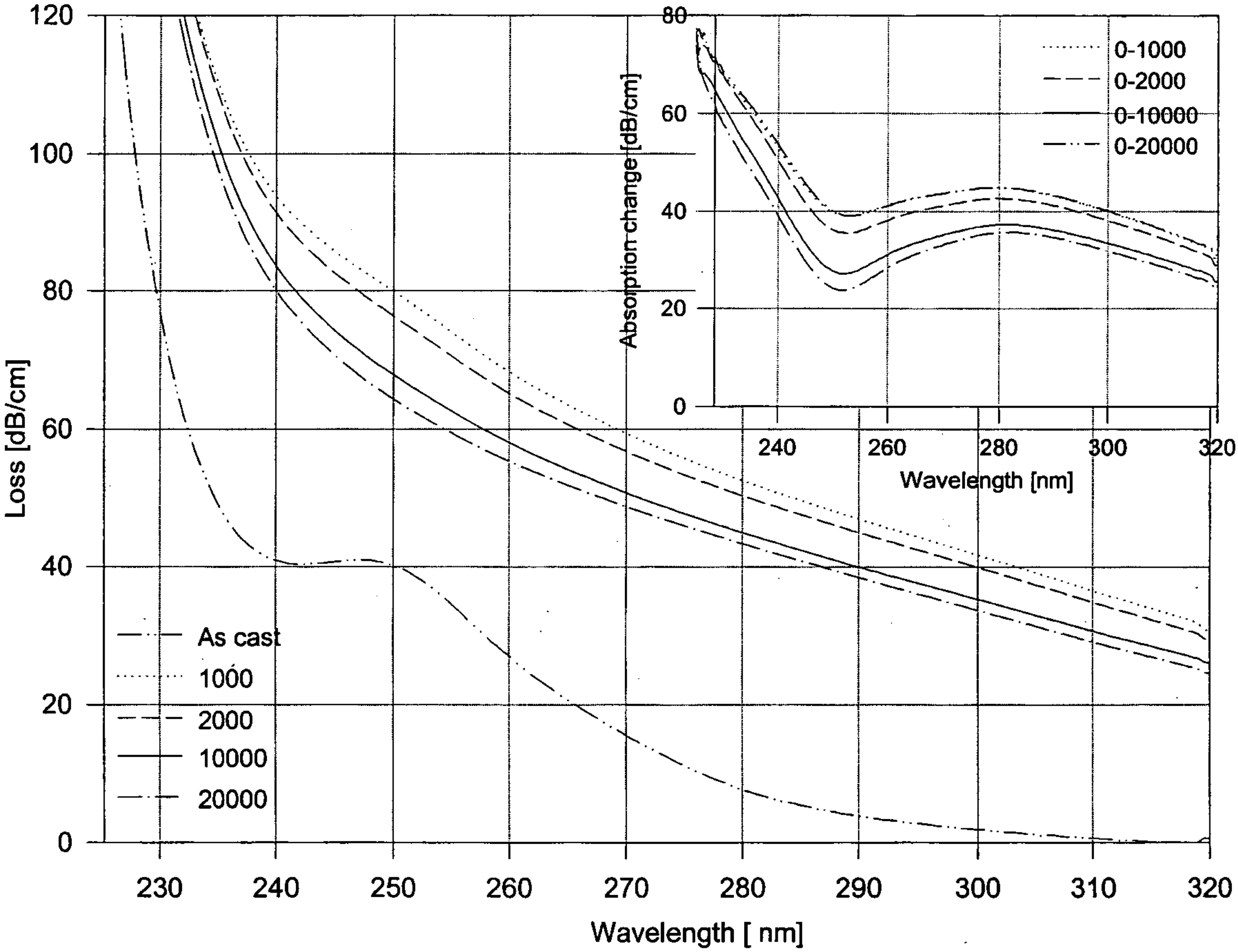


Fig. 3 – UV absorption spectra of SGBN20 (~155μm thick slice) vs. KrF excimer laser exposures (20Hz repetition rate, I_P ~ 100mJ/cm^2). Inset: UV induced absorption changes.

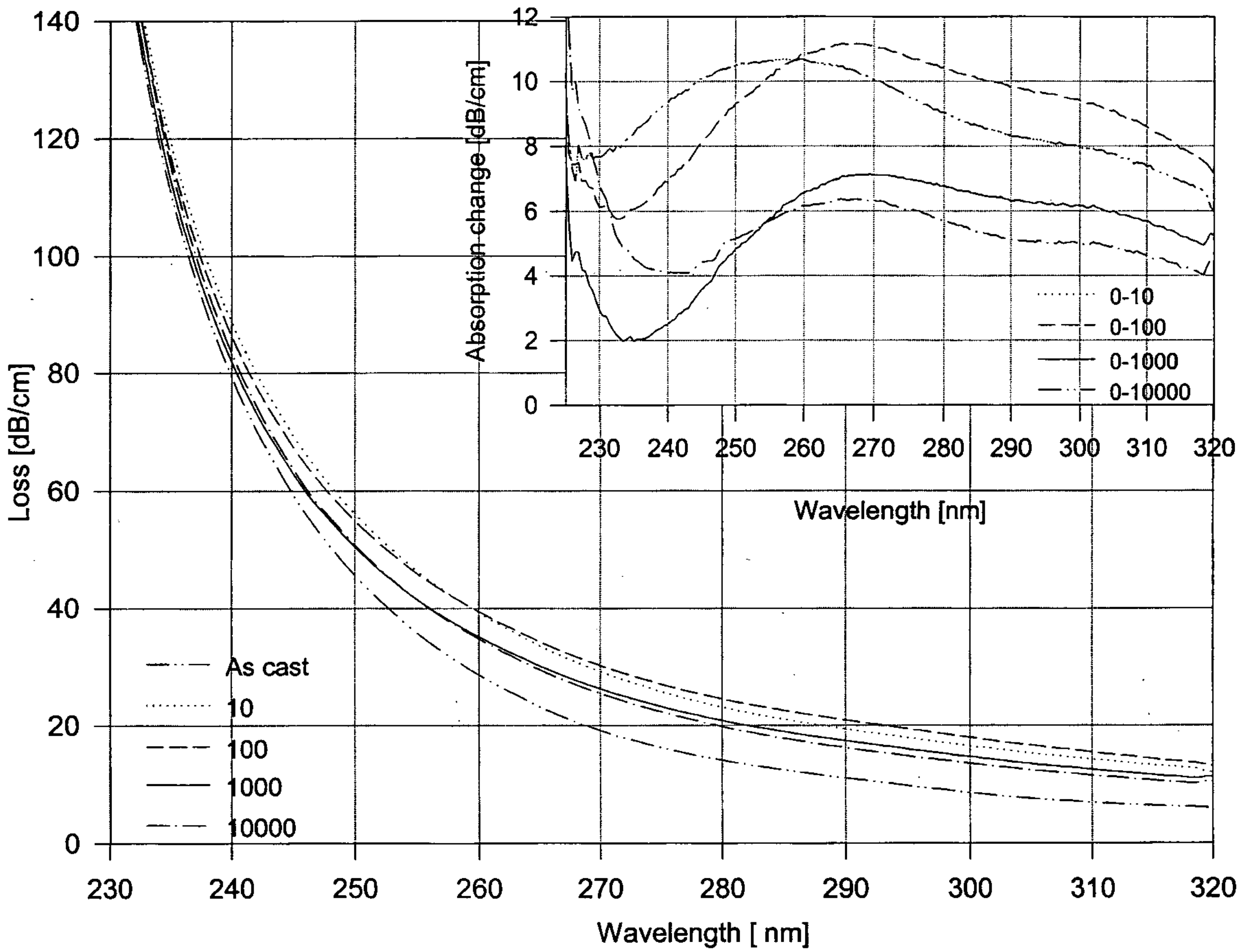


Fig.4 – Alpha step profile of SGBN20: channel 2 ,3 and 6 are labeled.

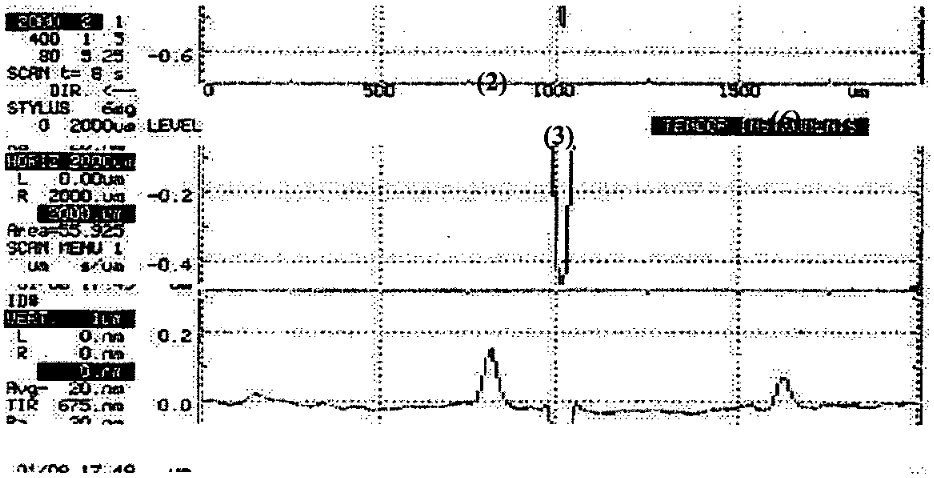
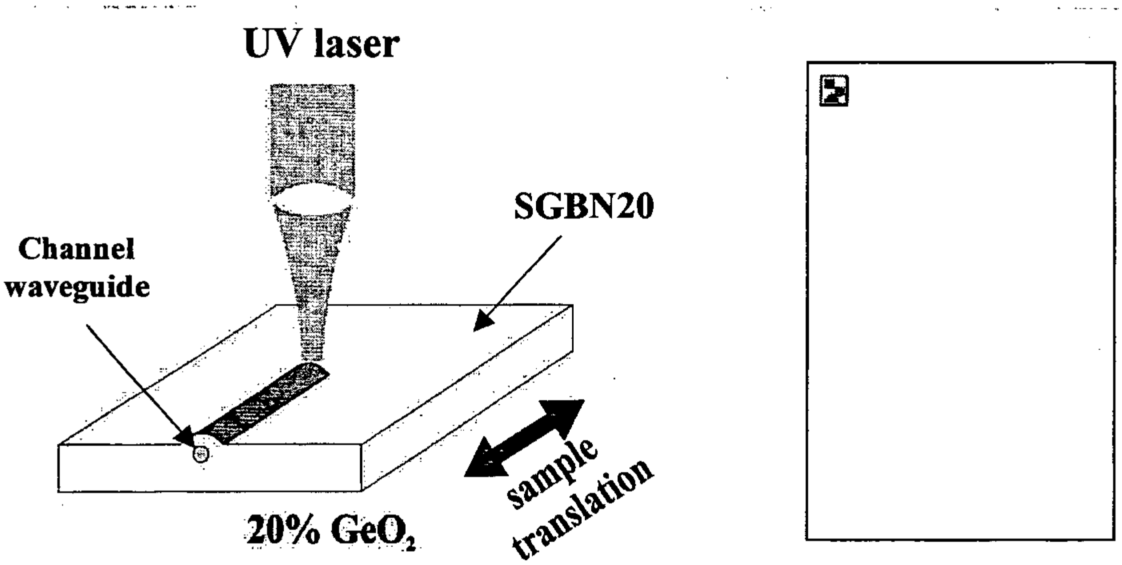
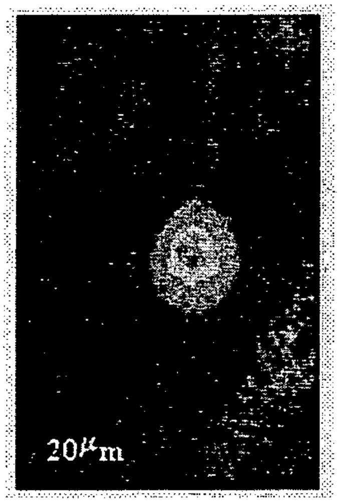


Fig.5 – (a) scheme showing the UV direct writing on the SGBN20 glass performed at 100mW and 30 mm/min; (b) image of the obtained channel waveguide (near field picture).

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