COMPARISON OF THE DECAY BEHAVIOUR OF NEGATIVE AND POSITIVE INDEX CHANCE FIBRE BRAGG GRATINGS

W.F. Liu, L. Dong, L. Reekie, D.N. Payne

We have studied the thermal stability of both negative and positive index gratings produced by a 193nm excimer laser. A complex decay process has been observed in gratings consisting of both types of index change. This phenomenon can be explained by our recently proposed three energy level model.

UV-written fibre gratings have many potential applications due to their high performance, and ease of manufacture. A phenomenological model is urgently required in order to optimise the grating design and manufacturing process. The fact that a grating with positive index modulation was formed first and then followed by a strong negative index modulation was found when a fibre was exposed to a ArF excimer laser ($\lambda = 193$ nm) [1,2].

We have proposed a three energy level (TEL) system to explain the grating growth in a boron-co-doped germanosilicate fibre written at 193nm [3]. This model is supported by our experimental observation including a negative index change following an initial positive index change and the growth rate of the index change being linearly proportional to the intensity of the writing beam. We have also found that the growth of negative index gratings written by an ArF excimer laser at 193nm is much faster than that written by a KrF excimer laser at 248nm [5].

From the TEL model, a positive index change is created by populating level 2 from level 1 (the ground level) and then the negative index change is obtained by populating level 3 from level 2. The populations of level 2 and 3 will eventually diffuse into nearby trapping sites. The population of level 3 is able to access significantly more stable traps than that of level 2.

Experimental results and discussions

The grating growth according to the TEL model is shown at the top right hand corner of Fig.1. It takes approximately 30 minutes to complete the grating growth by exposure to an ArF excimer laser at 193nm. The fluence was $0.3 J/cm^2$, repetition rate was 10 Hz and the grating length was 1mm.

Fig. 1 shows the decay characteristics of the gratings after short exposures to a range of temperatures. Six gratings having different exposure times (gratings A-F) were studied. Grating A was formed with mainly level 2 populated and its decay phenomenon is regular as shown in curve A of Fig.1. Grating B was created by stopping the exposure when the population in level 3 started to increase (curve B). Above 300°C, negative index changes dominated in grating B. This is due to the much quicker decay of the population at level 2 at elevated temperature than that of level 3.

The grating disappeared when the population of level 2 decreased enough to balance the negative index change. This effect can clearly be seen in curve C. For gratings D and E with the majority of their population in level 3, their thermal decay as shown in curves D and E grows steadily from 100°C to 400°C. We attribute this effect to the decay of the population in level 2 resulting in grating growth until the population in level 3 starts to decay. For grating F, the population is mainly in level 3 so the refractive index change is negative, and almost no decay was observed below 300°C.In order to get a more stable grating from one which has both level 2 and 3 populated,

W.F. Liu, L. Dong, L. Reekie, D.N. Payne are with the Optoelectronics Research Centre,Southampton University.

COMPARISON OF THE DECAY BEHAVIOUR OF NEGATIVE AND POSITIVE INDEX CHANGE FIBRE BRAGG GRATINGS

A.F. Lin, L. Dong, L. Reekie, D.N. Payne

We have studied the thermal stability of both negative and positive index gratings produced by a 193nm excimer laser. A complex decay process has been observed in gratings consisting of both types of index change. This phenomenon can be explained by our recently proposed three energy level model.

UV written fibre gratings have many potential applications due to their high performance, and ease of manufacture. A phenomenological model is urgently required in order to optimise the grating design and manufacturing process. The fact that a grating with positive index modulation was formed first and then followed by a strong negative index modulation was found when a fibre was exposed to a ArF excimer laser (λ = 193 nm) [1,2].

We have proposed a three energy level (TEL) system to explain the grating growth in a boron-co-doped germanosilicate fibre written at 193nm [3]. This model is supported by our experimental observation including a negative index change following an initial positive index change and the growth rate of the index change being linearly proportional to the intensity of the writing beam. We have also found that the growth of negative index gratings written by an ArF excimer laser at 193nm is much faster than that written by a KrF excimer laser at 248nm [4].

From the TEL model, a positive index change is created by populating level 2 from level 1 (the ground level) and then the negative index change is obtained by populating level 3 from level 2. The populations of level 2 and 3 will eventually diffuse into nearby trapping sites. The population of level 3 is able to access significantly more stable traps than that of level 2.

Experimental results and discussions

The grating growth according to the TEL model is shown at the top right hand corner of Fig.1. It takes approximately 30 minutes to complete the grating growth by exposure to an ArF excimer laser at 193nm. The fluence was [illegible], repetition rate was 10 Hz and the grating length was 1mm.

Fig. 1 shows the decay characteristics of the gratings after short exposures to a range of temperatures. Six gratings having different exposure times (gratings A-F) were studied. Grating A was formed with mainly level 2 populated and its decay phenomenon is regular as shown in curve A of Fig.1. Grating B was created by stopping the exposure when the population in level 3 started to increase (curve B). Above 300°C, negative index change dominated in grating B. This is due to the much quicker decay of the population at level 2 at elevated temperature than that of level 3.

The grating disappeared when the population of level 2 decreased enough to balance the negative index change. This effect can clearly be seen in curve C. For gratings D and E with the majority of their population in level 3, their thermal decay as shown in curves D and E grows steadily from 100°C to 400°C. We attribute this effect to the decay of the population in level 2 resulting in grating growth until the population in level 3 starts to decay. For grating F, the population is mainly in level 3 so the refractive index change is negative, and almost no decay was observed below 300°C. In order to get a more stable grating from one which has both level 2 and 3 populated,

W.F. Liu, L. Dong, L. Reekie, D.N. Payne are with the Optoelectronics Research Centre,Southampton University.

an annealing process can be introduced to remove the population in level 2. It is necessary therefore to study the population decay of levels 2 and 3 in more detail.

The thermal decay of positive index gratings for a range of temperature is shown in Fig.2 The gratings were exposed for approximately 30 seconds at 10 Hz to ensure that level 3 was essentially empty. In Fig.2, the total reflected power is monitored and then converted into a normalized coupling coefficient ($\varkappa$). From a power law function $\varkappa(t) = At^{\alpha}$ fitted to each curve of Fig.2. A and α are found to be $0.00173e^{0.00821T(\varkappa)}$ and $0.0153e^{0.00575T(\varkappa)}$ respectively [3]. Thus, the positive grating is expected to decay by 11 % over 25 years. In our experimental arrangement, annealing for 1 hour at 300°C will remove about 50% of the population in level 2 and the decay of level 2 can be neglected. A thermal decay measurement of the negative index gratings written with more than [illegible] minutes of exposure is shown in Fig. 3. The range of the test temperature is from 400°C to 600°C as there is no significant decay of the population of level 3 below 300°C.

Summary

We have confirmed that negative index gratings are more stable than positive index gratings from thermal stability measurements. In order to obtain more stable gratings, an annealing process can be used to remove the unstable part due to the positive index change.

References

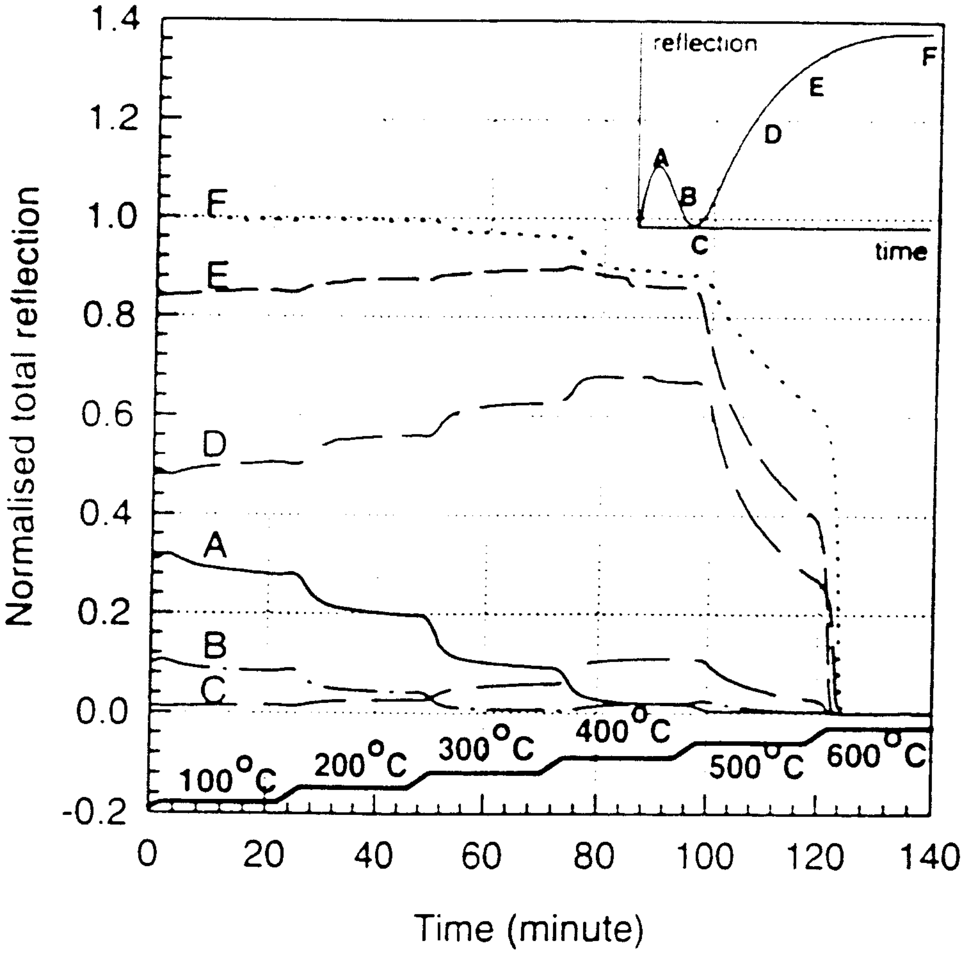
1 P. Niay, P. Bernage, S. Legoubin, M. Douay, W.X. Xie, J. F. Bayon, T. George, M. Monerie and B. Poumellec: "Behaviour of spectral transmissions of Bragg gratings written in germania-doped fibres: writing and erasing experiments using pulsed or cw UV exposure", *Opt. Comm.*, **113**, p.176, 1994.

L. Dong, L. Reekie, J.L. Cruz and D.N. Payne: "Grating formation in a phosphorous-doped germanosilicate fibre", Optical Communication Conference, paper TuO, San Jose, 1996.

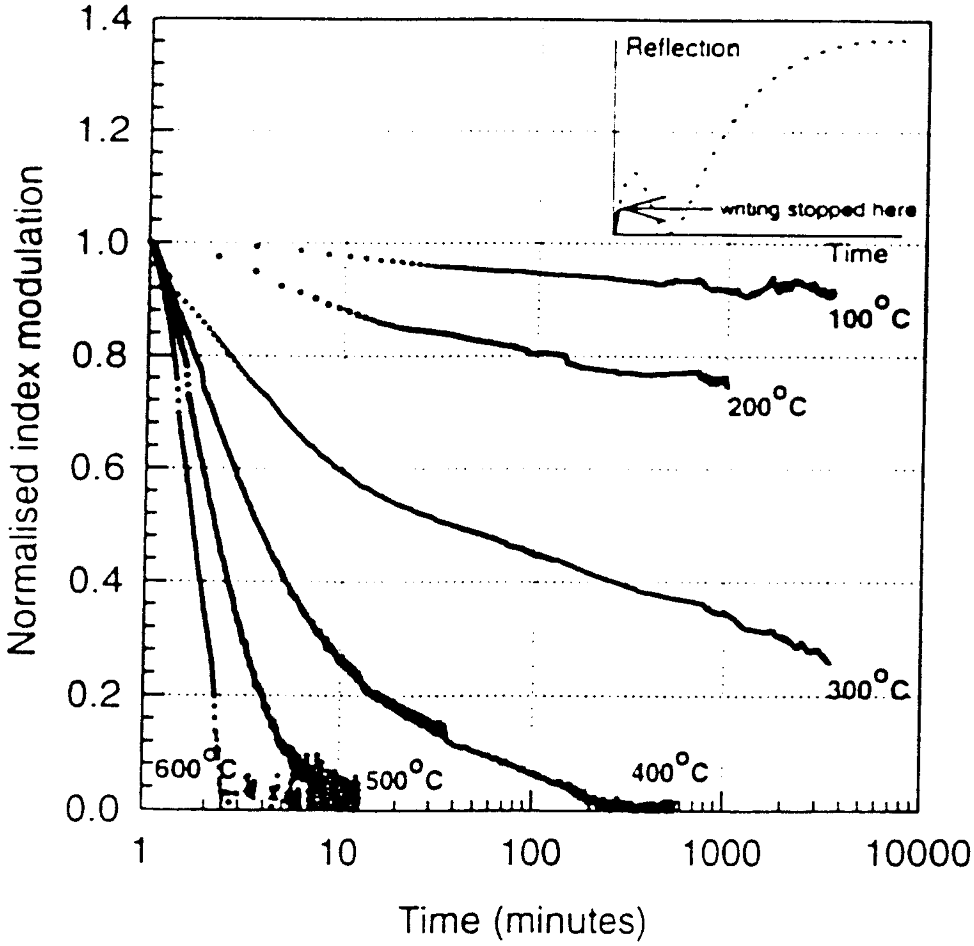
3 W.F. Liu, L. Dong, L. Reekie and D.N. Payne: "Complex decay behaviour of fibre Bragg gratings: further evidence of three energy level of photosensitivity in Germanium-doped optical fibres", ThJ7, OFC'97

4 T. Erdogan, V. Mizrahi, P.J. Lemaire and D. Monroe: "Decay of ultraviolet-induced fibre Bragg gratings", *J. App. Phys.*, **76**, p.73, 1994.

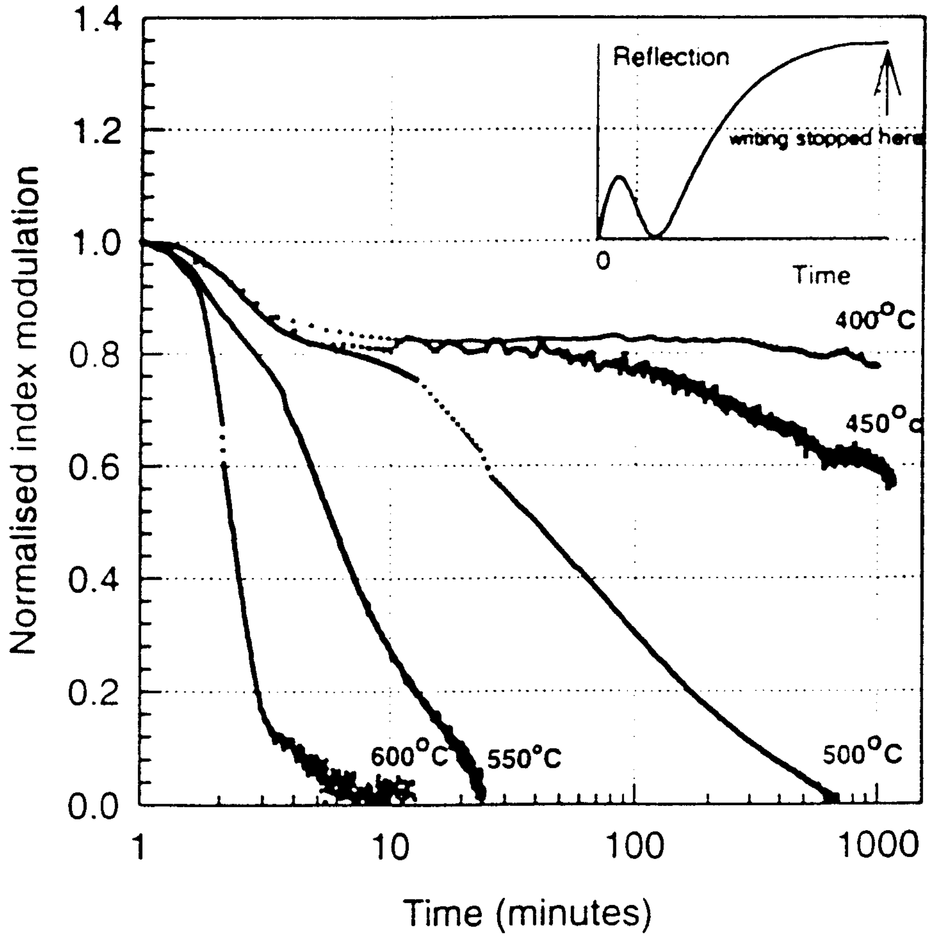
W.X. Xie, P. Niay, P. Bernage, M. Douay, J.F. Bayon, T. Georges, M. Monerie and B. Poumellec: "Experimental evidence of two types of photorefractive effects occurring during photoinscriptions of Bragg gratings within germanosilicate fibres", Optics Communications, **104**, pp185-195,1993.



reflection
time
A
B
C
D
E
F
Normalised total reflection
Time (minute)
100°C
200°C
300°C
400°C
500°C
600°C
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0
20
40
60
80
100
120
140



Reflection
writing stopped here
Time
100°C
200°C
300°C
400°C
500°C
600°C
Normalised index modulation
Time (minutes)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1
10
100
1000
10000



1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Normalised index modulation
1
10
100
1000
Time (minutes)
Reflection
writing stopped here
0
Time
400°C
450°C
500°C
550°C
600°C