Investigations on annealing for optimal Bragg grating Regeneration

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Abstract: The influence of annealing schedule on regeneration of grating and its optimisation for maximum strength and stability has been studied. An optimum temperature for regeneration is found. The Arrhenius relaxation is characterized by a single exponential indicating a net single glassy relaxation; to explain these observations we suggest at lower temperatures viscous flow inhibits relaxation restricting the index change possible below the optimal temperature window for relaxation between processed and unprocessed regions of glass.
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1. Introduction

Regeneration of fiber Bragg gratings (RFBG) has been investigated for over a decade [1-8]. Erasing of Type-I grating at elevated temperatures has been understood in detail in the past, while the subsequent regeneration phase has been rather intriguing throughout because of the thermally stable changes possible through post annealing. Various available doped fibers have been tried [1-4] but the simple Ge-doped standard single mode fiber was found to produce most stable regeneration as of now. This is consistent with a general principle of mixed glass states being less stable than single material glass systems and both silicon and germanium oxides are closest matched. In parallel, several different annealing schedules have been tried in pursuit of producing high quality regenerated grating [5-7], and till date the regenerated grating reflectivity could be enhanced to greater than 80% following isothermal annealing of Type-I gratings inscribed in standard Ge-doped single mode fibers using 248 nm [8] and 193 nm [9] UV radiation. Gratings have been regenerated at different temperatures and generally it was observed that the regeneration strength was always higher at lower temperatures, suggesting optimization of the particular relaxation retaining FBG contrast. Now the question is how far is it possible to lower the temperature and improve regeneration? Is it possible to reach to 100% reflectivity simply by lowering the temperature? The answer turns out to be no.

In this paper we have shown that regeneration strength as a function of annealing temperature has a turnaround point or roll over; i.e. the strength is maximum around a certain temperature and the strength decreases for any temperature which is either lower or higher than that. This is an important observation because it reflects the combination of contributions in grating regeneration that influence the overall structural relaxation involved. Only diffusion cannot justify this because the regeneration degrades both at higher temperature and at lower temperature as well.

2. Experimental results

Standard Ge- doped single mode fiber (SMF-28-e of Corning Inc.) with ~3 mol. % GeO_2 in the core was used for fabrication of Type-I seed gratings. Prior to grating inscription, fibers were hydrogen loaded (1500 psi, 80 ^{0}C for 48 hours). A set of four gratings were fabricated with similar transmission loss (TL ~ -50 dB). A diode pumped solid state Q-switched $Nd:VO_4$ laser operating at 213 nm (Impress 213, Xiton- Photonics GmbH) was used for FBG inscription. The gratings were annealed by tubular furnace (OTF-1200 X: MTI Corporation) and a thermocouple was used for measuring the temperature of the furnace. Gratings were annealed individually by inserting into a pre-heated oven. The annealing temperatures for different gratings were at 950 ºC, 860 ºC, 810 °C, 760 °C and 710 °C respectively. Peak reflectivity of the gratings and the Bragg wavelength were recorded throughout the annealing cycle. Figure 1 (a-d) have shown the variation of reflectivity of RFBG as a function of time at different annealing temperature.

Figure 2 shows the regeneration strength or the peak reflectivity recorded at different temperature. The result is consistent for seed gratings inscribed using 213 nm and 248 nm. It is interesting to see that the turnaround point, i.e. the temperature around which the peak reflectivity is obtained is lower for the lower UV wavelength, e.g. ~810 ^{0}C for 248 nm and ~760 ^{0}C for 213 nm. It is also important to note that for the case of 193 nm UV wavelength the peak reflectivity was achieved around 700 ^{0}C but unfortunately no data was available for other lowerer temperatures [9]. So peak regeneration is a function of temperature and the inscription wavelength as well. Figure 2c shows the temperature dependence of the regeneration time for the case of fig 2a.

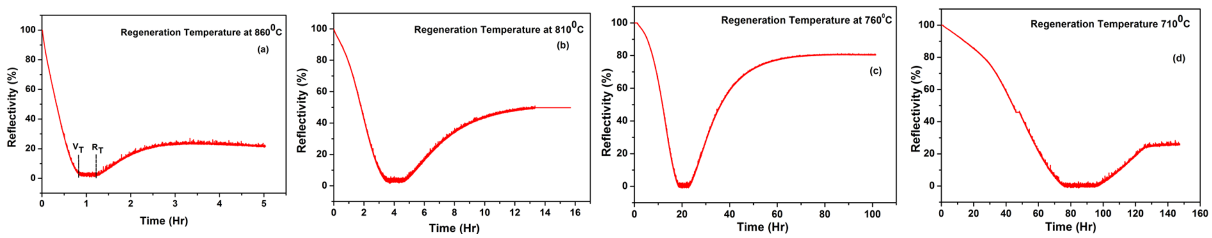

Fig. 1. (a-d) Grating decay and regeneration at four different temperatures

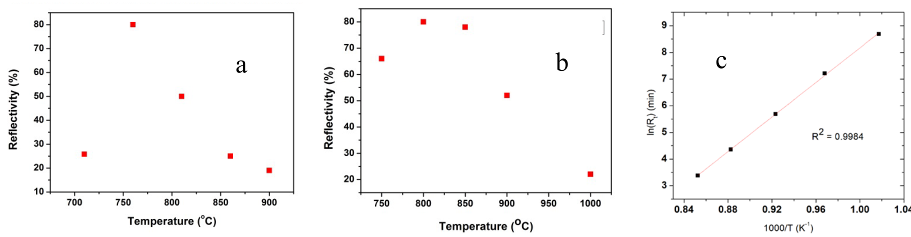

Fig. 2. Variation of reflectivity at different temperatures (a) for 213 nm (b) for 248 nm, (c) Plot of ln(R_t) vs. 1000/T; R_t is the time to regenerate and T is the annealing temperature

3. Discussion

Overall the presence of an optimal annealing process for regeneration whilst retaining a single Arrhenius relaxation is consistent with a single relaxation phase in a glassy system – that system will have different end network outcomes as a result of the conditions. Ordinarily it might expected that the lower the temperature the more selective the particular relaxation phase is in a complex system but in this work evidence of other factors also influencing the optimization of the relaxation between processed and unprocessed regions appear present. This can be explained by noting that viscosity will play an increasing role at lower temperatures and so an optimum relaxation point might be expected. More detailed structural studies of the glasses, including the associated forensic defects, can provide additional insight.

4. Conclusion

5. References

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