Observation of Replica Holes in Erbium Doped Silica Fiber

T. P. Mayer Alegre, G. S. Wiederhecker, A. A. Rieznik and, H. L. Fragnito

Laboratório de Comunicações Óptica, Departamento de Eletrônica Quântica, Instituto de Física "Gleb Wataghin" UNICAMP, Campinas, SP Brasil.

gsw@ifi.unicamp.br

Abstract

We observed for the first time to our knowledge the presence of replica holes in the fluorescence spectrum of EDFA. Saturating the Er^{3+} transition at a single wavelength we noticed the appearance of spectral holes in the ASE other than the usual one around the saturating laser. We qualitatively explain the effect and confront the experimental results with the homogeneously broadened model.

Introduction

One of the limiting factors to state-of-the-art DWDM systems is the effect of Spectral Hole Burning (SHB) in Erbium Doped Fiber Amplifiers (EDFAs). It has been already observed that the presence of a saturating signal in a given wavelength induces a hole around the signal in the gain and Amplified Spontaneous Emission (ASE) spectra [1],[2]. These holes in EDFAs are typically between 2 and 8 nm width, which is enough to degrade the neighboring channels. The SHB effect is due to the inhomogeneous broadening of the Er^{3+} transitions, caused by site-to-site variations of the local electric field in the silica based host, which induces different ions laser lines properties.This work shows the existence of spectral holes burned at wavelengths far from the saturating laser line, called Spectral Replica Holes (SRHs). The physical background that explains SRHs is based on the inhomogeneously broadened two-level Stark Splitted $^4I_{13/2} \rightarrow {}^4I_{15/2}$ Er^{3+} laser transition. When a signal interacts within two Stark sublevels of a given subpopulation of ions, it saturates this transition (Figure 1), and also inhibits the other transitions of this subpopulation of ions. Once the signal induced stimulated emission reduces the upper level population of this ions, holes are created around the laser line (SHB) and at other wavelengths (SRH), where the saturated ions have peaks in the Emission and Absorption Spectra.

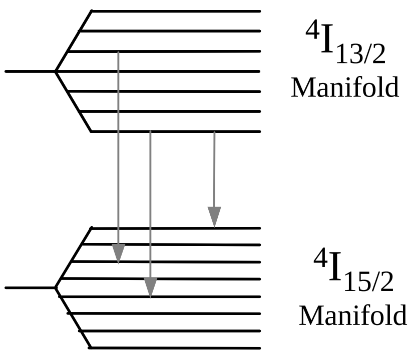


Figure 1: Stark-split energy levels showing the possible transitions between upper and lower manifolds.

Experimental Setup

The technique used to characterize the SRHs consists in measuring two different ASE spectra: one with a high power (~0 dBm) saturating laser (Figure 3-a) tuned at 1580 nm, and the other saturated with a laser at 1530 nm, for example. Adjusting the power of the latter we minimize the difference between these two ASE spectra, ensuring that both have the same compression (Figure 3-b). The measurements were made at room (300K) and low (77K) temperature (Figure 2). The latter made possible decreasing the phonon level in the fiber, reducing the homogeneous linewidth and clearing, thus, the SHB and SRHs effects.The fiber used was a 3 meters length EDF co-doped with lanthanum and aluminum with peak absorption of 18.6 dB/m and pumped by 50 mw power at 980nm. With this short fiber we ensure the ASE is not inducing self-saturation in the Amplifier, which could affect the legitimacy of the technique.

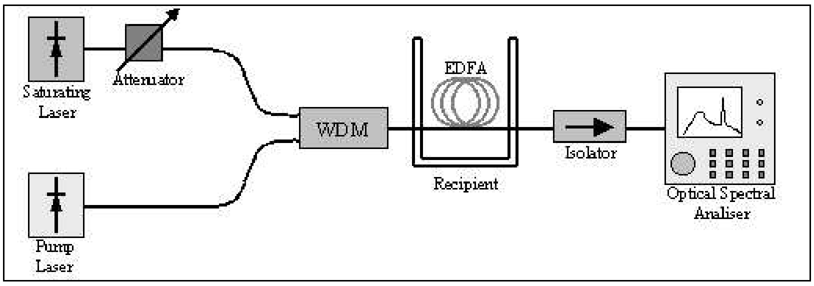


Figure 2: Experimental setup, when we made measures in low temperature the recipient was fillet with liquid nitrogen.

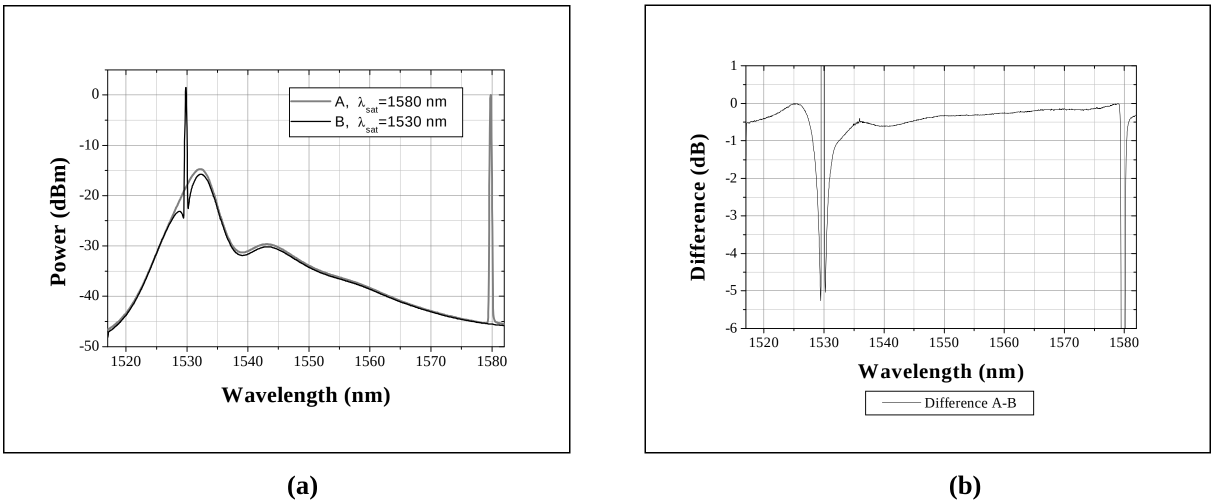


Figure 3: (a) The reference curve (low temperature), named A, with –5 dBm laser tuned at 1580nm and a spectrum, named B, with 0 dBm laser tuned in 1530nm. (b) Difference between both spectra (A-B).

Results and Discussions

If the transitions in the medium were only homogeneously broadened and the ASE self saturation effects could be neglected, it wouldn't be observed any hole in Figure 3-b, which can be proved applying the procedure described above, but employing simulating ASE curves generated by an homogeneously broadened model [3] (Figure 4).

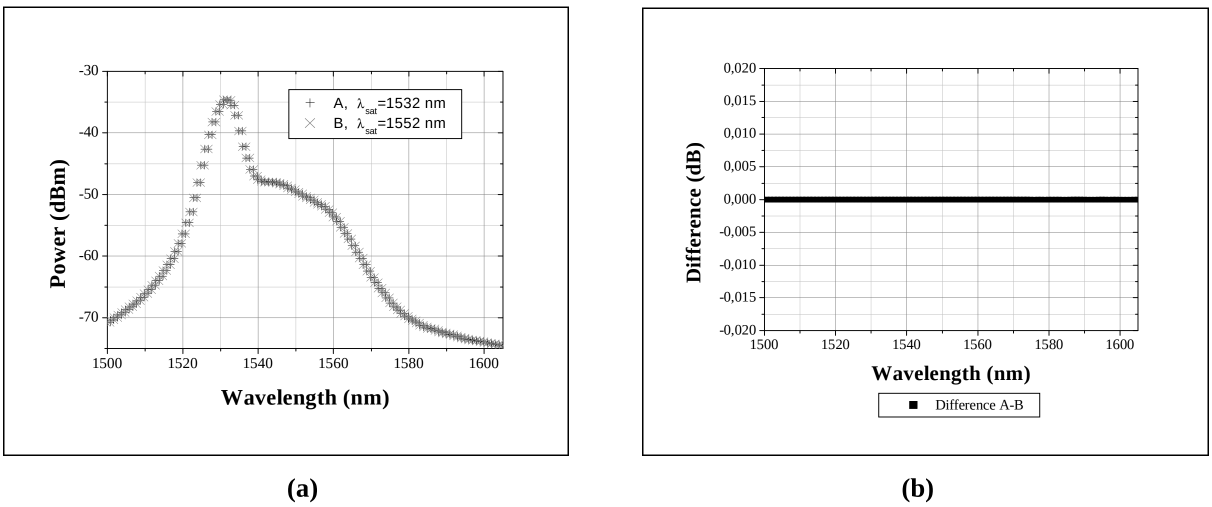
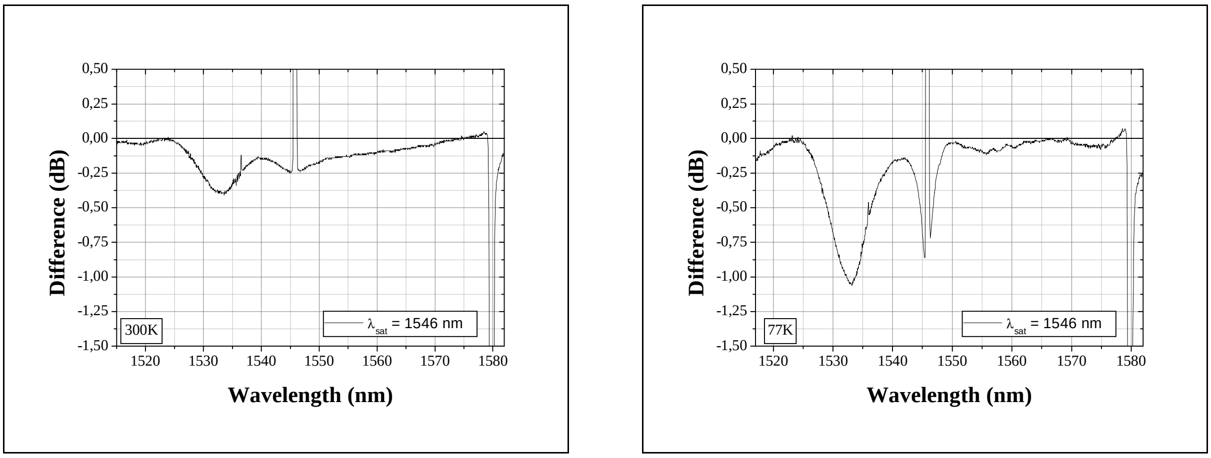


Figure 4: (a) Simulated curves generated by commercial software based on the model proposed in [3]. We simulated a 3 m typical EDF pumped at 980 nm by 200 mw, and the following saturating signals powers and wavelengths: 0 dBm @ 1552 nm and –2 dBm @1532 nm,. (b) Difference between the two simulated curves.

Based on these results we ensure that any hole appearing in the measured difference spectrum is due to inhomogeneous broadening.

To characterize SRHs we measured a reference spectrum with the saturating laser at 1580 nm, and many other spectra varying the saturating laser between 1520nm and 1580 nm. Then, we applied the technique described above to each pair of spectra. Figure 5 shows one example of these difference spectra at room temperature and one at 77 K, both with the saturating signal at 1546 nm. A SRH it is clearly observed at ~1532 nm.



(a) **(b)**

Figure 5: (a) Some results obtained at room temperature (300K) with the methodology described. (b)Same results but at low temperature (77K).The SRHs induced around 1530 nm clearly has it depth and shape changed in both graphics when the tunable laser is tuned at 1546 nm.

Figure 6 shows the depth of the SRH at 1532 nm as a function of the saturating wavelength. As we discussed above, when a transition of a given subpopulation of ions is saturated, it is inhibit the resonant one and the others of this subpopulation. Figure 6 shows, then, the emission and absorption spectral shape of the subpopulation of ions with peak absorption and emission at the observed wavelength (1532 nm), i.e., the homogeneous cross-sections spectral shape [1]. Therefore, the procedure we adopt to graph the curves in Figure 6 can be employed as an easy and non-destructive way to measure homogeneous cross-sections in EDFs.

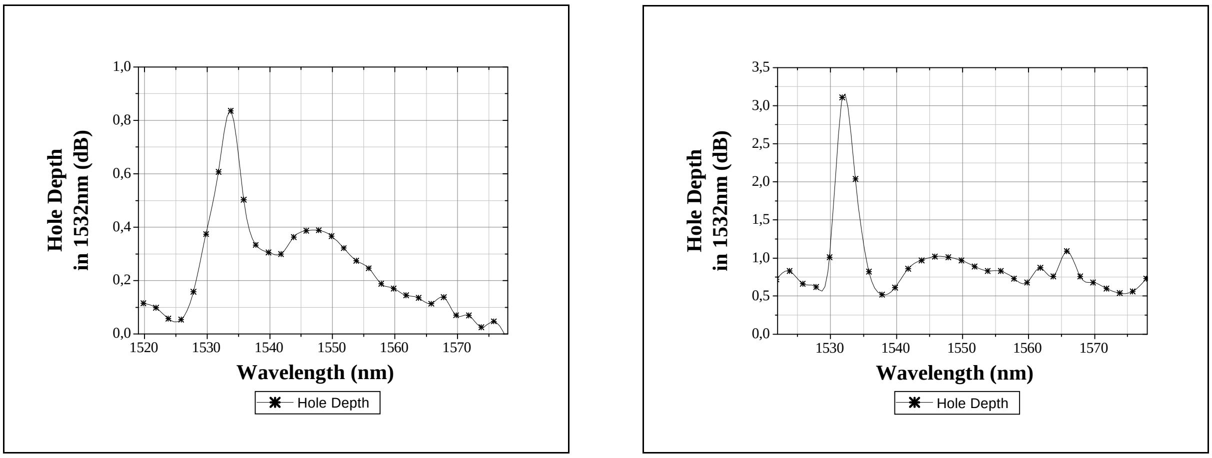


Figure 6: Hole depth at 1532 nm as a function of the saturating signal wavelength (a) at room temperature and (b) at 77K.

Conclusions

We demonstrate experimentally and theoretically the existence of SRHs in EDFs. SRHs have a practical consequence in the prediction of DWDM optical systems and will impact the design of optimal gain dynamic equalizer filters. We also showed how to employ SRHs to measure the homogeneous cross-section in EDFs and, although our new techniques was not quantitatively study, we already show that it can be employed to have a first guess of the homogeneous cross-section spectral shape. We are working on a more detailed study of the SRHs effect.

Acknowledgements

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References

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