Exciton lifetime of 4H-SiC modified by thermal annealing in high pressure O_2

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1. INTRODUCTION

Silicon Carbide (*SiC*) is an advanced material belonging to the family of **Ultra Wide Bandgap** semiconductors known for its excellent characteristics and a promising material for high power applications due to its potential to improve the energy efficiency and lowering energy consumptions. For these reasons, there is a rising interest from researchers and industry to synthesize good quality wafers with high carrier mobility and low defect density. For electronic applications a thin oxide gate is needed, which is usually produced by Chemical Vapour Deposition (CVD) of SiO_2 . It is crucial that the defect density at the interface between SiC and SiO_2 is as low as possible to mantain good electrical characteristics. Therefore, several **Post Deposition Annealing (PDA)** methods have been developed to passivate and reduce these defects located on the interface between oxide and semiconductor. However, these methods usually involve high temperature (1100- 1300 °C) thermal annealing in gases as NO, N_2O, $POCl_3$ at atmospheric pressure for a short time interval. Here we present a different PDA conducted at low temperature (**400 °C**) in an high pressure (**50 bar**) pure $\boldsymbol{O_2}$ atmosphere. This method could provide valuable insight on the fundamental oxidation properties of SiC and at the same time offer a cost-effective alternative to standard PDA.

2. METHODS

The presence of defects in SiC crystal lattice induces variations in the vibrational modes, that can be highlighted using **Raman spectroscopy**.

It is also possible to evaluate the quality from the **exciton lifetime $\boldsymbol{\tau}$**. In our experimental setup (**Fig. 1**) we measure the PL intesity decay as a function of time after the excitation pulse. The PL intensity follows:

$$I(t) = I(0)\exp(-t/\tau)$$

We conducted **thermal treatments** in high pressure O_2 atmosphere ($300 - 800\ PSI$) in a reactor like in **Fig. 2**.

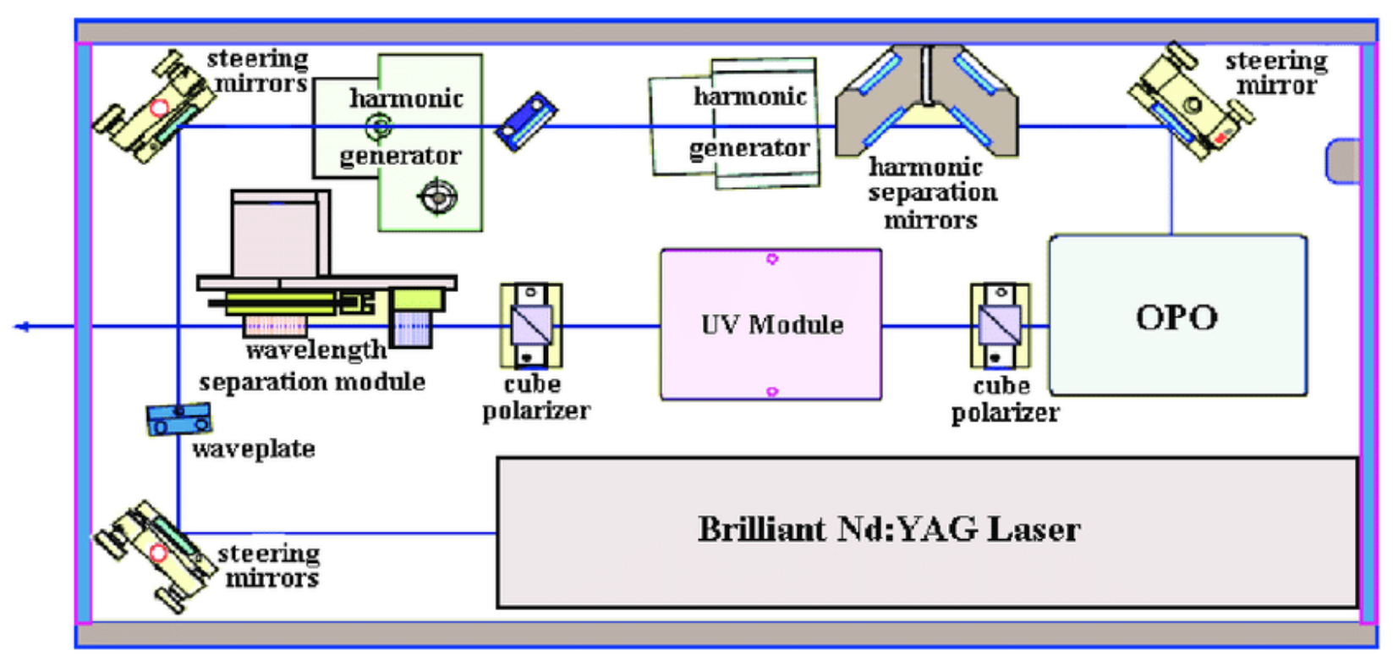
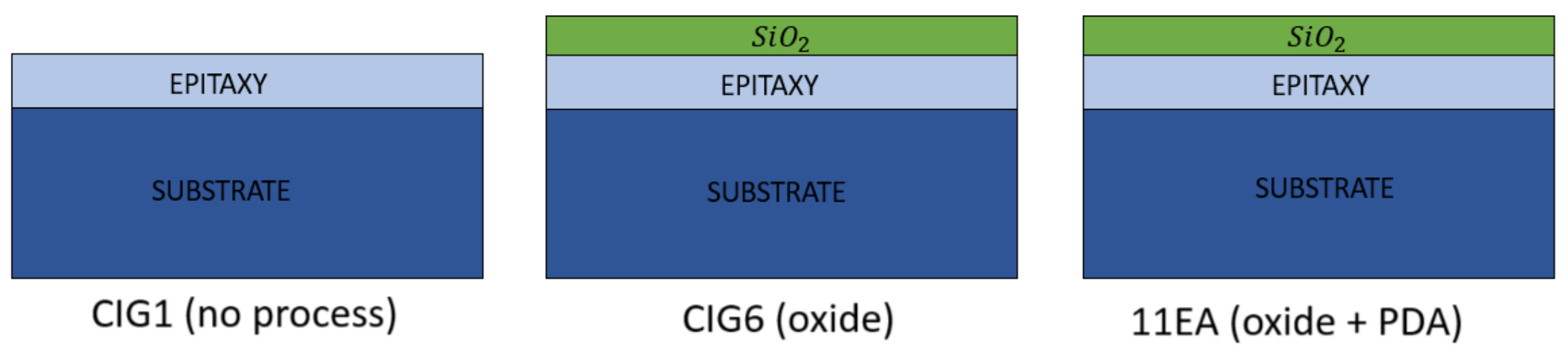


Figure 1: Schematic of tunable laser system used for TRPL

Figure 2: Parr reactor for thermal treatments

3. SAMPLES

Samples studied in this work are representative of three steps in the production line of SiC wafers.



- **CIG1**: Epitaxial layer of SiC on a highly-doped substrate
- **CIG6**: a 50 nm SiO_2 layer is deposited on the epitaxial SiC layer
- **11EA**: subjected to thermal annealing (PDA) in NO in order to improve electrical characteristics

6. CONCLUSION

- Samples show two different initial exciton lifetime before thermal treatments
- Different results were obtained for pressure above or below $P_{crit}(O_2) = 730\ PSI$

SAMPLE	RESULTS
CIG1	τ decreases for $P > P_{crit}$
CIG6	τ increases for $P > P_{crit}$
11EA	τ not affected by thermal treatments

- Thermal treatment at $P = 300\ PSI$ shows no change in lifetime
- CIG6 undergoes a recovery process similar to that obtained with NO PDA

Further studies will involve a more in-depth analysis on the time-dependence of this thermal annealing process, XPS characterization and electrical parameters measurements.

4. CHARACTERIZATION

Comparing samples' Raman spectra, we can see (**Fig. 3**) that in the Longitudinal Optical Phonon Coupled (LOPC) mode ($\sim 980\ cm^{-1}$) a "shoulder" appears on the right in samples with oxide layer (CIG6, 11EA). Given that the LOPC mode is highly sensitive to doping,[1] this feature could be attributed to an increased density of defects at the SiC/SiO_2 interface and can give us information about the different doping levels between epitaxial layer and substrate.

When excited at $\lambda = 266\ nm$, samples show an emission peak centered at 390 nm (**Fig. 4**) due to excitonic recombination. We want to follow the time evolution of this excitonic recombination process under the assumption that the **mean lifetime $\boldsymbol{\tau}$** is a quality indicator of the material:[2,3] high τ means low defect density and vice versa.

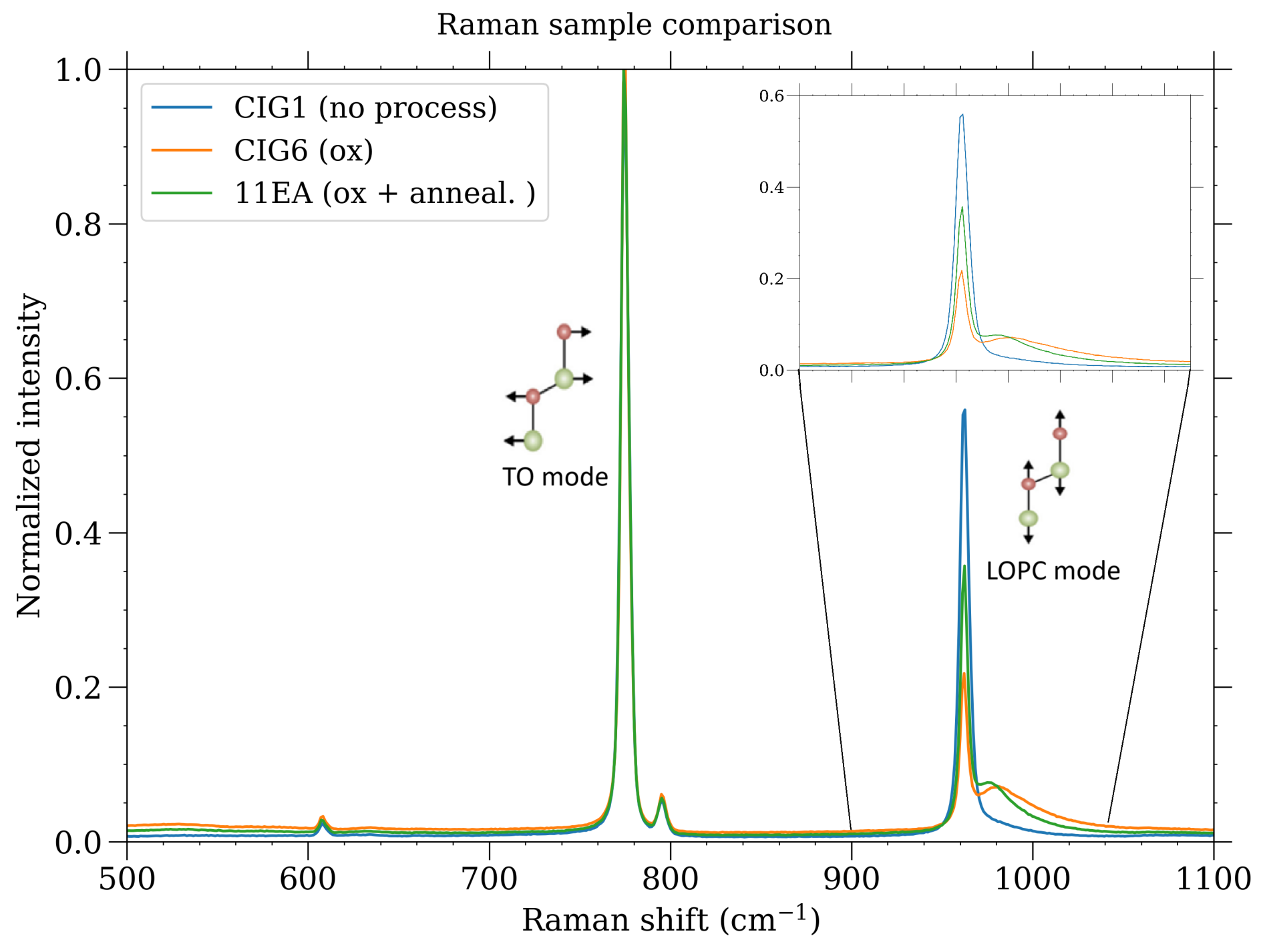


Figure 3: Raman spectra, comparison between samples.

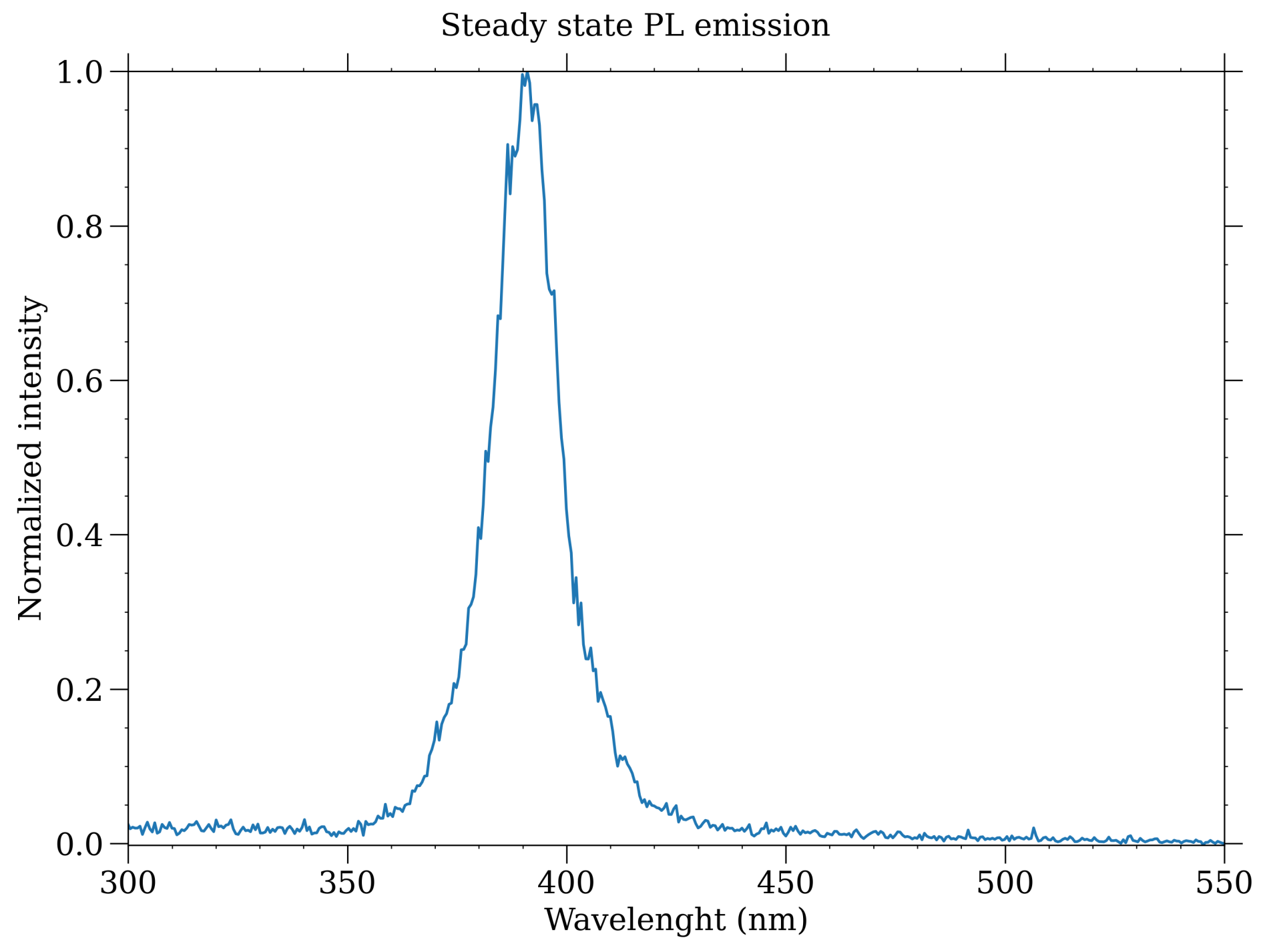


Figure 4: Steady state PL emission showing a single peak centred at 390 nm.

5. RESULTS

A first characterization on as received samples shows that CIG1 and 11EA have higher lifetime $\tau = 20\ ns$ compared to CIG6 which has $\tau = 10\ ns$ (**Fig. 5**)

For each sample, thermal annealing process is performed in $\boldsymbol{O_2}$ at T=400 °C for different pressures and durations.

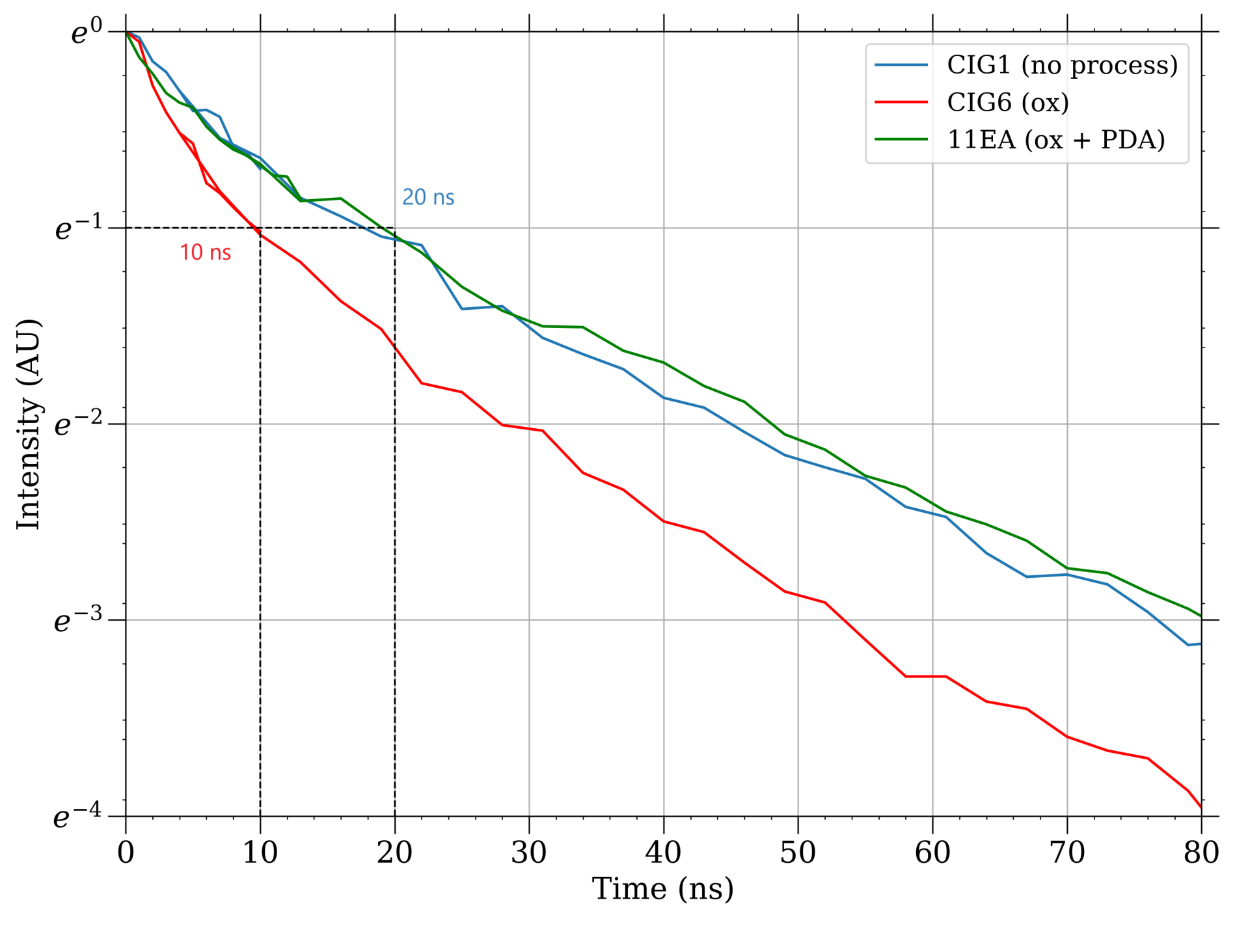


Figure 5: As received sample

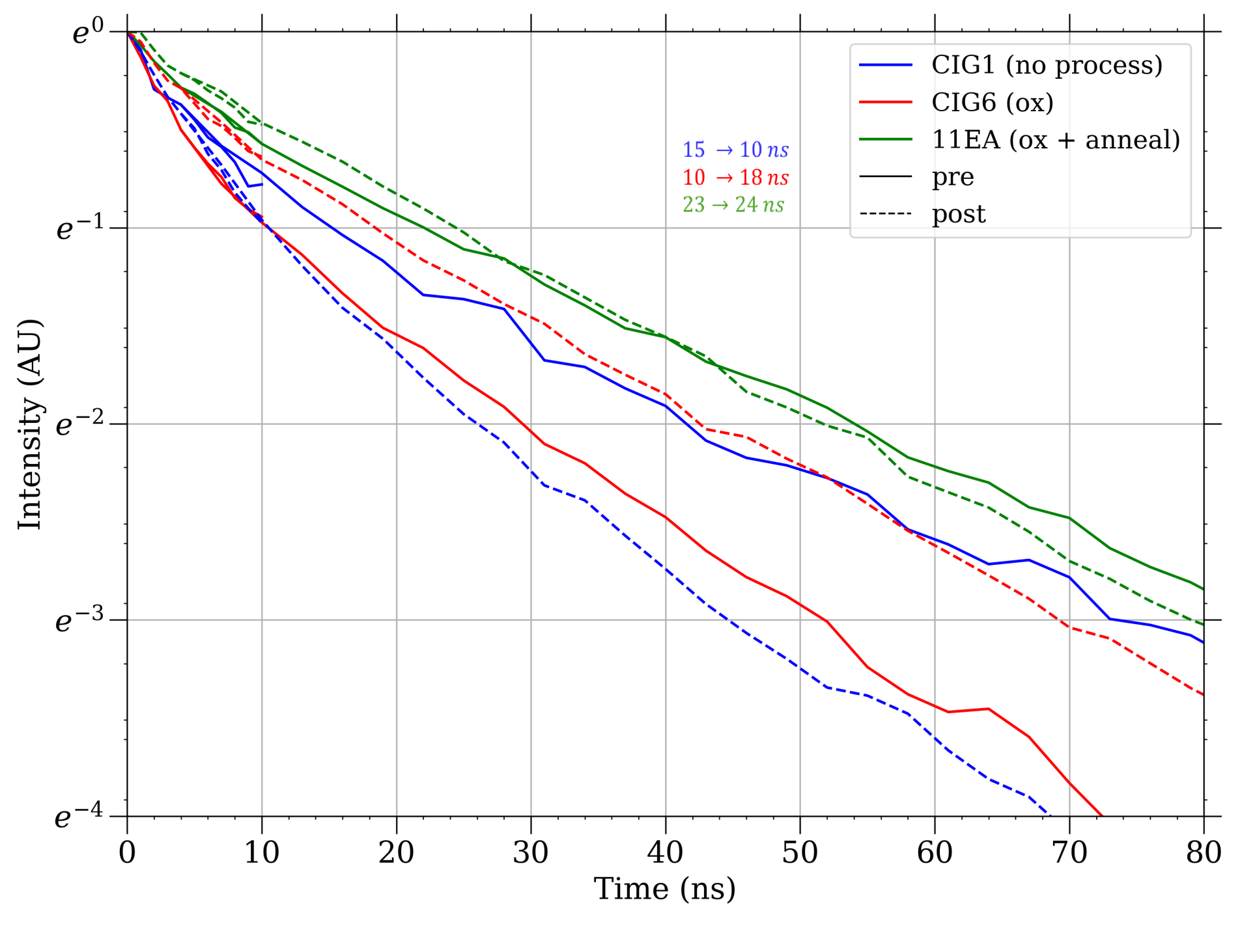


Figure 6: T=400 °C, P=800 PSI, t=48h

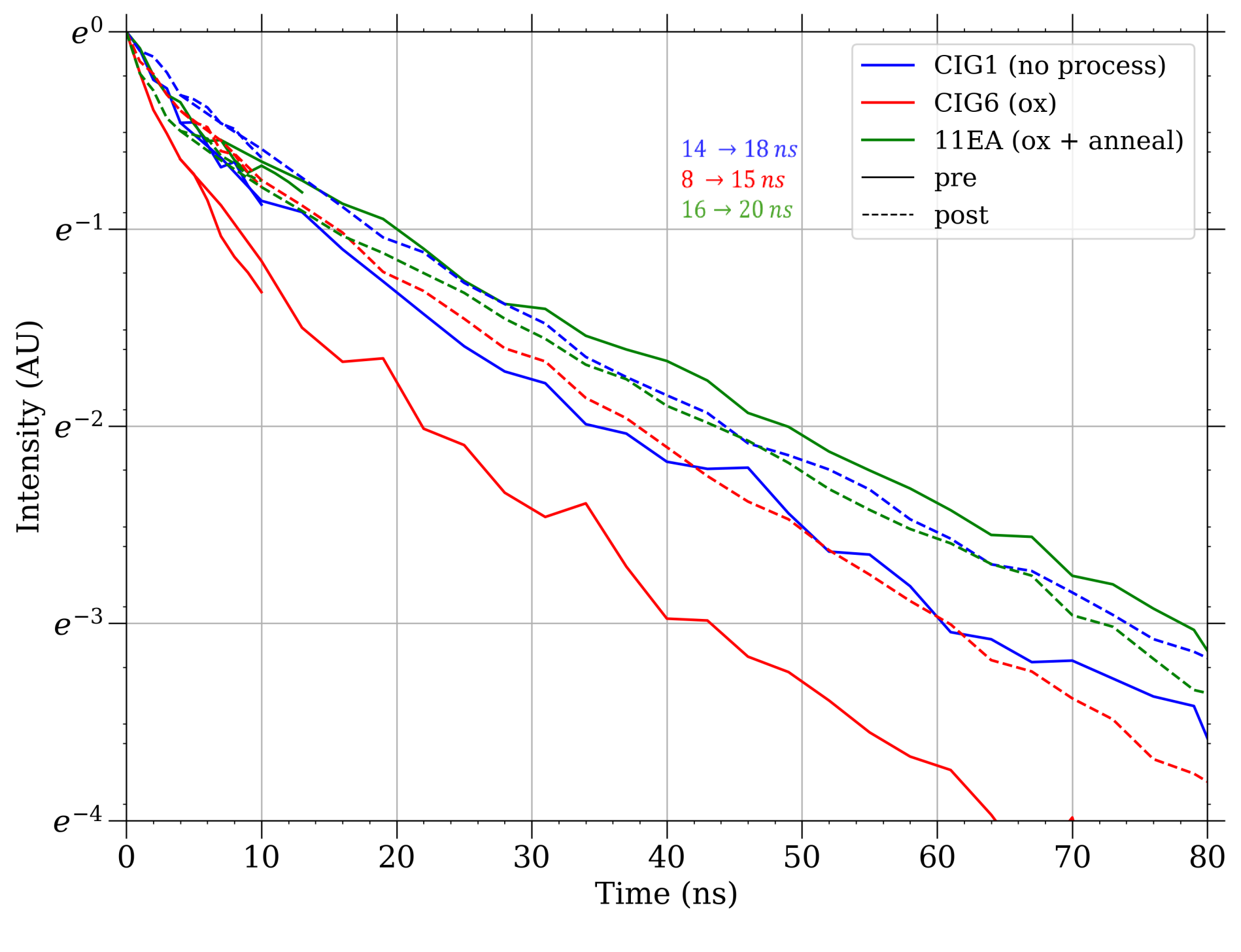


Figure 7: T=400 °C, P=800 PSI, t=2h

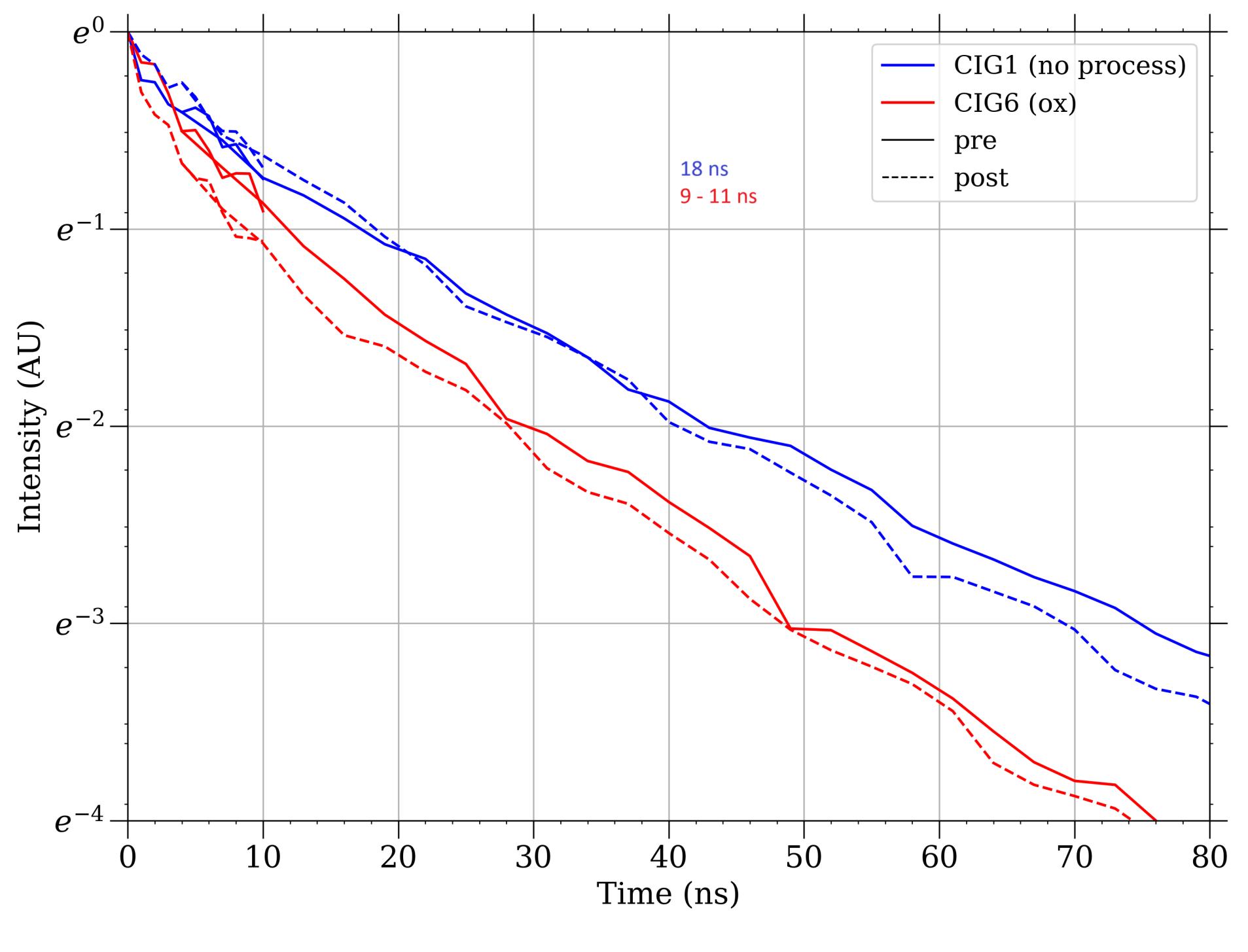


Figure 8: T=400 °C, P=300 PSI, t=2h

5. REFERENCES

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