

Reuse of cover glass from end-of-life photovoltaic panels to produce glass-ceramics with innovative properties

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REPORT INFO

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ABSTRACT

Oxyfluorides containing up to 75 wt% of recycled glass from end-of-life solar panels have been investigated. Reduced processing temperature and high transparency have shown that the material has potential for optical applications. In this work, Raman demonstrated that cerium affects the glass network by promoting polymerization. In turn, thermal analysis indicated some changes in the crystallization events between 500-800 °C, which were confirmed by in situ X-ray powder diffraction measurements. Crystallization of fluorite, xonotlite, and combeite was confirmed, while other phases give minor contributions to the XRD patterns. Cerium addition reduced the formation of xonotlite, mainly above 700 °C. The potential applications of the material and the further studies required are discussed.

1- Introduction

The world has been experiencing rapid growth in solar electricity production, but researchers have shown that this rate is insufficient to meet our greenhouse gas reduction targets [1]. The industry faces several challenges in scaling up the production of photovoltaic solar panels, including the production of flat glass itself [2].

More specifically, the flat glass used in solar panels, which from now on we will call “solar glass”, requires high-purity raw materials compared to other applications, as iron and other impurities can compromise the transparency of the glass and, consequently, the electricity output of solar panels [3,4].

Today's solar glass production is about 24 million tons annually, and it should be

multiplied by 3-4 to keep pace with the expansion of photovoltaics and keep global warming below 2 °C [2,5]. To put that in perspective, the total glass output of the European glass industry is about 40 million tons [6]. It is challenging to separate the glass from the other materials in end-of-life solar panels [5], and unwanted mixing impurities can inhibit the recycling of these materials [7,8]. Other specific challenges are related, for example, to antimony, which has been used to produce solar glass [5] and may pose an environmental threat to some reuse routes for this material [9].

To achieve more sustainable practices for end-of-life solar glasses, one potential alternative is to develop new glasses and glass-ceramics that use solar glass as a raw material. In previous

work, we reported the production of a series of oxyfluoride glasses (CgCAF), composed of up to 75 wt% of cullet from solar glass [10], which was previously extracted from a photovoltaic panel [11]. The melting temperatures of the samples decreased significantly upon the introduction of CaF_2 and Na_2CO_3 , yielding high transmittance over a wide range, enabling these samples to be explored for a variety of applications.

2- Experimental details

Samples were prepared using high-purity raw materials from Sigma Aldrich, as described in our previous work [10]. Several trials at the CEMHTI involved annealing these samples at different temperatures and measuring them during or after the treatments.

A JASCO FP-8550 fluorometer was employed to perform spectroscopic measurements in transparent disc samples. An integrating sphere (ISF-134) was used to obtain the absorbance from reflectance data. Emission and excitation measurements were performed using the standard cell holder (SCE-146), in which glass disc samples were mounted on a metallic support.

A Renishaw INVIA REFLEX Raman spectrometer with a 1800 lines/mm diffraction grating was used to obtain Raman spectra with a 514 nm laser.

DSC was performed in a SETARAM Multi HTC 1600. Powdered samples were placed in a Pt-Rh crucible and heated to 850 °C at 10 °C/min under argon (20 ml/min).

In situ HT XRPD analysis was performed on powdered material to evaluate the temperature-dependent structural evolution. The measurements were performed in the Bragg–Brentano θ - θ geometry on a high-flux SmartLab Rigaku rotated Cu anode diffractometer equipped with the HypiX-3000 HE detector and an Anton Paar oven chamber (model HTK 1200N, Graz, Austria), which allows measurements up to 1200 °C. Powders obtained from crushed glass beads were placed in a platinum-lined corundum sample holder. Data were collected from 500 °C to 800 °C with a 20 °C step size, an angular range of 10-80 ° with a 0.016 ° step size, and a speed of 1 °/min.

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3- Results and discussion

Figure 1 shows images of samples produced in Brazil and investigated at the CEMHTI.



Fig. 1. Transparent CgCAF samples (top) and the same samples under UV light irradiation (bottom)

During the execution of this project, samples were submitted to measurements as described in the experimental section. Several results were collected; the investigation continues. Specifically, some samples are currently under investigation at CEMHTI by “nuclear magnetic resonance” (NMR), and other studies will be carried out at UTFPR in Brazil in the next few months.

In summary, the ensemble of experiments provided background on the behavior of CgCAF glasses at high temperatures. Inside the glass volume, the material has been shown to remain quite stable upon heating, with crystallization detected only at the surface and above 600 °C. The main crystalline phases identified were Fluorite, Xonotlite, and Combeite. The controlled crystallization of this phase is under investigation, and we have already produced CgCAF-Xonotlite glass-ceramics, which are currently being investigated by NMR.

4- Conclusion

The findings from the CgCAF samples collected at the CEMHTI during the execution of this project have already been presented to the scientific community and are under evaluation in one of the top journals on glass-ceramic materials. Besides that, many more experimental data remain under analysis and should be suitable for publication in the months to come.

Another valuable aspect concerns the experience provided with new techniques and the exchanges with the CEMHTI personnel. These exchanges are driving new research directions for some projects, and PhD students at UTFPR are already developing them.

5- Perspectives of future collaborations with the host laboratory

In April 2026, a meeting was held at the CEMHTI to discuss further developments related to this project. A few other Brazilians who collaborated in this project were invited, and during the visit, they could see the facilities and the potential to develop their own projects in partnership with the CEMHTI.

The main follow-up was the consolidation of a team to prepare a project for the “CAPES-COFECUB” program. This has been the main mechanism for funding Brazil-France academic partnerships for decades, and our project under this call will involve three universities in Brazil, the CEMHTI, Université d’Orléans, and Université de Limoges. One of the partners in this project, Professor Robson Muniz, will also visit Orleans as an invited researcher of the Université d’Orleans for two weeks next autumn.

The continuity of this project on the reuse of cover glass is ongoing research, and the partnership with the CEMHTI remains.

6- Articles published in the framework of the fellowship

The collaboration between UTFPR and the CEMHTI began prior to our proposal for the Smart Loire Valley. This early work resulted in a publication entitled “Oxyfluoride glasses obtained through incorporation of CaF₂ into photovoltaic cover glass melts”, published last year [10].

Some results were also presented at the “International Conference on Glass 2026”, held in Lyon from April 13 to 17. A full research article entitled “Upcycling solar glass into Ce-doped oxyfluorides: spectroscopic properties and crystallization properties” was submitted to the “Journal of the American Ceramic Society” and, by April 2026, was under review. This

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work is also publicly available, as submitted, as a preprint [12].

A collection of data remains unpublished, and other studies are underway in France and Brazil related to this fellowship project. These are likely to result in other scientific outputs soon.

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