Production of glass nanofibers from fragile melts by Laser Spinning

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New one-dimensional nanostructured materials are continuously investigated in search of new and improved applications [1, 2]. Laser Spinning is a new technique which we developed for the production of ultralong amorphous ceramic nanofibers with lengths up to several centimetres. This technique allows large quantities of nanofibres to be made with specific, controllable chemical compositions. This will potentially open up a whole new range of applications for the fibres.

The fundamentals of the technique will be outlined. It employs a laser to melt a small volume of a solid precursor material while a high pressure gas jet drags it. Thus, the molten material forms glass fibres as result of its viscous elongation by the drag force and rapid cooling by the convective heat transfer promoted by the gas jet. Figure 1.a exhibits a SEM micrograph showing the typical morphology of the fibres. They form a disordered mesh of intertwined fibres with different diameters, typically in the range from tens of nanometres up to several microns. Each fibre has a uniform well-defined cylindrical morphology of near constant diameter with smooth surface, as can be observed in the TEM picture presented in Fig. 1.b. Due to the high cooling rate the final structure is amorphous as the diffraction pattern in the inset of TEM micrograph demonstrates.

We performed a comprehensive study of the process which led us to a precise control of the technique. Specific control of the process allows for the production of amorphous nanofibers of non-ready glass former materials and the unprecedented synthesis of glass nanofibers from very fragile melts. The study of the process involves two main analysis [3, 4]: an experimental evidence on the mechanism of formation of the nanofibers was obtained using a high speed camera to record the formation of microfibers in some milliseconds; secondly, the process of fibre formation was mathematically modelled by applying the basic theories of elongational flows to the specific case of uniaxial stretching during melt blowing. The mathematical model allows extrapolating the experimental evidences obtained for the production of microfibers to explain the formation of the nanofibers in a matter of microseconds. The dimensions and temperature of the molten volume together with its viscosity to surface tension ratio are revealed to be the controlling factors for the formation of the nanofibers.

More specifically, the competition between the elongational flow which produces the nanofiber, and the break-up flow driven by the capillary forces which leads to the filament split into spheroidal particles, is shown to be the key factor controlling the technique for the production of nanofibers from fragile melts. Figure 2, shows a frame from a high speed video which illustrates the actual competing progress of the elongational and the break-up flows. From a critical analysis of the mathematical modelling it is inferred that the viscous forces work against the capillary forces and they must be improved to produce the nanofibers. For this reason, it is crucial to study the temperature-viscosity data of the melt in order to adjust the parameters controlling the Laser Spinning process. In this presentation we will outline the method to control the Laser Spinning process with the aim of producing glass nanofibers from very fragile melts which can not been formed into fibers by any other technique. This outcome opens up a range of capabilities for the synthesis of glass nanofibers with different compositions with applications in the field of biomaterials [5], catalysis, textiles or materials for energy.

References

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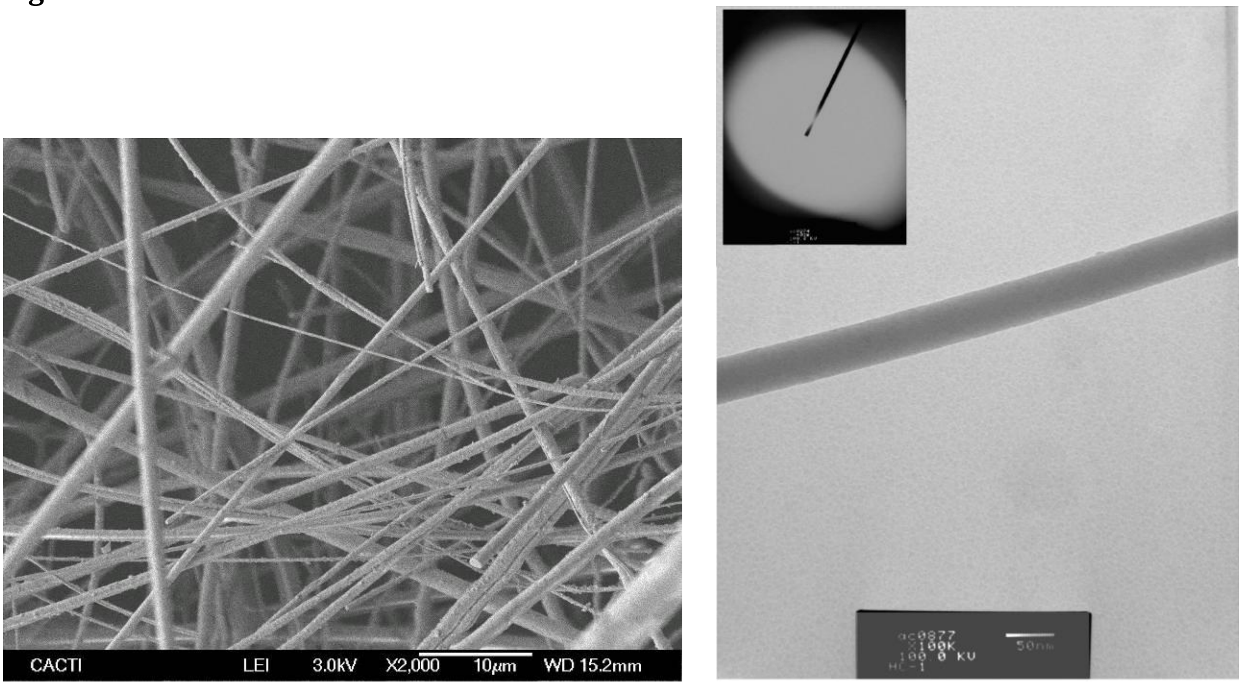
Figures:



a) **b)**

Figure 1. a) The SEM micrograph presents the typical appearance of the micro- and nanofibres produced by means of the Laser Spinning technique. b) The TEM micrograph shows a detail of a nanofibre with a diameter of 35 nm and the inset shows its amorphous structure.

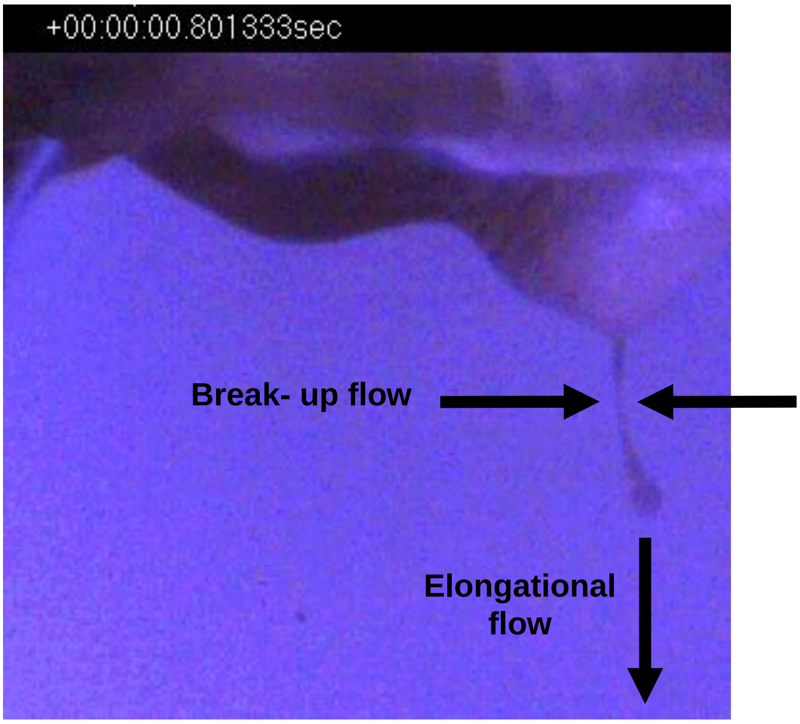


Figure 2. The high-speed camera frame shows the precise instant where the effect of the two competing flows can be observed acting on a viscous filament of the molten material. The break-up flow driven by surface tension forces tends to split the filament while the elongational flow driven by the gas jet pulls to form a nanofiber.