The Market of Ceramic Nanofibers

Ebrahim Alizadeh Head of R&D at Advanced Energy Minerals, Fariba Safizadeh, R&D Manager at Advanced Energy Minerals, **Dante Maestre** Market Intelligence Manager at Advanced Energy Minerals Inc., **Mark Fearns** Technical Marketing Manager at Advanced Energy Minerals.

The nanofibers sector is growing at a pace normally reserved for industry leading technologies, despite its modest presence in the modern material landscape. In the last 3 years, the market for nanofibers has grown from 1.5 bn USD in 2018 to the current 2.5 bn USD valuation and will continue throughout 2026 with a CAGR close to 20%. North America, especially, The United States, plays an important role due to prominent medical applications, which represent the most important sub-sector from a technological point of view.

Nanofibers are normally defined as nanoscale solid-state structures with a high aspect ratio and high surface area to volume ratio. They are traditionally defined as cylindrical (hollow or solid) structures having the outer diameter less than 1000 nm, and more typically less than 600 nm, with an aspect ratio often greater than 50. These features lead to a material with a very large surface area and it is this, along with imparting excellent mechanical properties, that makes it suitable to be used in a number of sectors, such as: energy, medical, electronics & optoelectronics, and sensors, among others. From a material point of view, nanofibers can be made from a variety of materials by applying different synthetic approaches, as listed in Table 1:

Material Type	Synthesis	Features	Applications
Carbon nanofibers	Produced via chemical vapour deposition or by electrospinning of organic polymers and subsequent thermolysis.	High specific surface area, mechanical flexibility, high strength.	Composite materials, aerospace, energy storage, electrochemical sensing, water filtration, biomedical.
Ceramic nanofibers	Mostly composed of alumina or zirconia, produced via magnetron sputtering, air jet spinning and electrospinning.	High specific surface area, excellent thermomechanical properties, high porosity, photocatalytic activity (via doping with TiO_2)	Aerospace (thermal insulation), filtration, catalysts support.
Glass nanofibers	Laser electrospinning.	Controlled and uniform diameter. Relatively inert vs chemicals.	Acoustic and vibration damping, insulation in electronics, biomedical, water filtration.
Polymer nanofibers	Melt spinning, electrospinning.	High surface area, high strength and flexibility, porous structure, tailorable surface structure.	Filtration, tissue engineering, energy storage.

Table 1: Nanofibers by material and application.

This article aims to provide an overview on the most interesting type of nanofibers from a purely technological point of view, which is ceramic nanofibers.

In recent times, ceramic nanofibers have been used in a spectrum of applications owing to the particularly high thermal stability and high porosity of the articulated material. Among the functional applications, it is worth mentioning the use of gas sensors, capacitors/dielectrics, piezo-electrics, membranes for water and air filtration, microwave shielding, energy harvesting and storage, miniaturised electronic devices, and catalysts. Ceramic nanofibers can also be structured as ceramic textiles, and that allows the creation of a large class of formats such as rovings, yarns, sewing threads, fabrics, adhesive tapes and braided sleeving.

Ceramic nanofibers are, like aerogels, ceramic nanostructured materials and can be obtained out of oxides, nitrides and carbides as summarized in Figure 1.

Most of the time ceramic nanofibers are obtained by electrospinning of alumina slurries and with small amount of SiO_2 added to the dispersion to stabilize the crystal and inhibit its growth. Alumina fibers are ultra-light weight, high-temperature stable insulation materials.

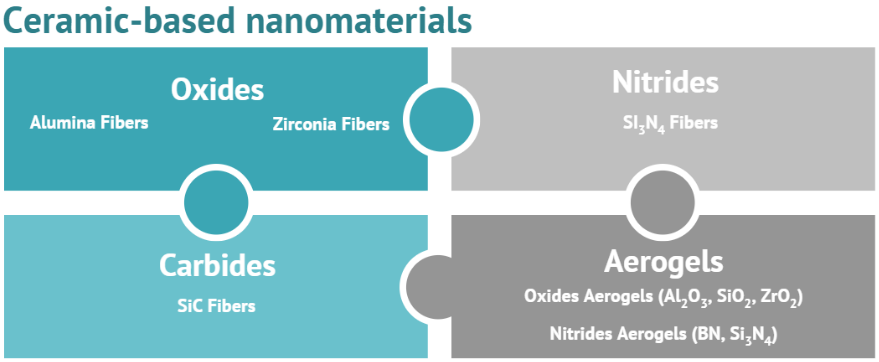

Figure 1: Diagram showing fragmentation of the applications of ceramic-based materials.

Moreover, alumina fibers have relatively low thermal conductivity, low heating shrinkage, good chemical stability, good high-temperature resistance, and because of this are often used in the insulation of nuclear reactors and space shuttles. These very special applications require materials to withstand temperatures above 1500 °C, which is a temperature far too high for the conventional aluminosilicate fibers, used as thermal insulation. In addition, they can also be used as catalyst carriers for the chemical industry; one notable example is the ceramic nanofibers developed by 3M, marketed under the brand name Nextel, which exhibit excellent dimensional stability and low thermal conductivity, as well as non-porous and non-hygroscopic characteristics. These advanced nanofibres retain their flexibility even at continuous temperatures of up to 1300°C, which makes this material suitable for aerospace applications.

Another important feature that has been greatly exploited by the catalyst-manufacturers is the relatively easy doping with transition metals in the form of metal catalyst nanoparticles distributed on the surface area of the ceramic nanofibers. For this type of application, the purity of the precursor (alumina oxides) is of great importance, in fact, some fine chemical applications require a purity of 99.99% or more. The conventional manufacturing process requires that the metal precursor is dispersed in a solvent or water (high purity required) prior to the electrospinning process. After spinning, the ceramic precursors are randomly dispersed and partially buried throughout to produce metal nanoparticle-doped nanofibers. The metal catalyst so obtained will then be heated in air to a sufficiently high temperature of about 200 °C to 1,200 °C.

In terms of manufacturing processes, many efforts have been devoted recently to the development of processes for ultra-fine alumina fibers with a diameter of a few nm so that the fiber itself has great flexibility and specific surface area. In addition, certain unique structures can be obtained by tailoring the calcination, which could alter fiber properties, thus their performance, as illustrated in Figure 2:

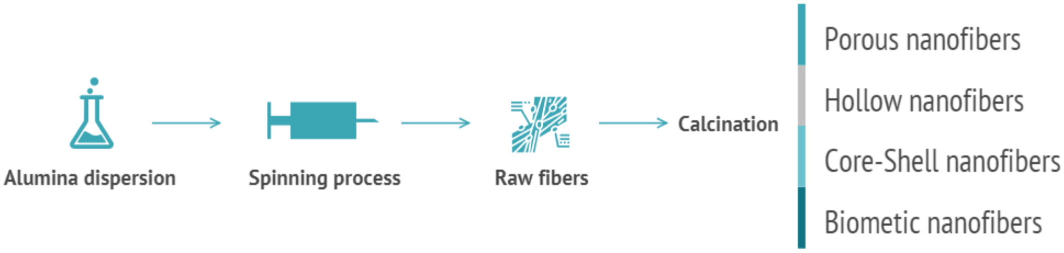

Figure 2: Diagram showing the broad production process for aluminous fibers.

One interesting new frontier in the ceramic nanofibers sector is represented by the formation of sponge fibers which are often used as additive for ultra-light composites, though it is important to mention that currently most of sponges are made of zirconia rather than of alumina (zirconia-based fibers). From the application point of view, the nanofibers with the greatest market potential seem to be represented by alumina nanofibers mixed with liquid electrolytes in lithium-ion batteries. In fact, there is a plethora of literature on oxide ceramic nanofiber films, obtained by sol–gel electrospinning technology, showing absorption of electrolytes (in some cases being greater than 900% of the weight of the fibers). These unique features may result in high thermal insulation performance, dramatically improving the safety of lithium-ion batteries.

The future of ceramic nanofibers appears bright, with continuous research and technological advancements driving their untapped potential. Ceramic fibers represent a promising sector poised for steady growth in the coming years, despite their relatively small market size, which is estimated to be less than 50 million USD annually, and still very small compared to the overall nanofiber market. The academic and industrial interest surrounding ceramic nanofibers stems from the vast possibilities offered by novel production processes, enabling the creation of sophisticated and finely crafted materials with advanced technological properties.