Turning Nanofibre Into Products

I. Hosie*

*Revolution Fibres Ltd, 9A Corban Avenue, Henderson, Auckland, New Zealand
iain@revolutionfibres.com

ABSTRACT

Revolution Fibres Ltd is New Zealand's premier advanced materials company and a global leader in nanofibre production. Its mission is to enable companies to produce superior products using Revolution Fibres' designed functional nanofibres. Revolution Fibres has commercialized products with various clients in the areas of filtration, skin health, composites, acoustics, biotech and anti-allergy bedding.

Nanofibre has huge potential. Most often created through a process called electrospinning, it can be readily functionalized, has incredible physical properties, and is very marketable. It is also easy to produce at research level – hence the high number of papers and patents in this field. But is the level of innovation reflective in examples of commercialization? Revolution Fibres is one company that bridges the gap between research and commercialization, focussing on manufacturing and product development with advanced materials for real-world benefit.

Keywords: nanofibers, advanced manufacturing, advanced materials, electrospinning, nanotechnology.

1 INTRODUCTION

In recent years, the interest in nanofibre research and development has grown dramatically, with new nanofibrous materials and applications being reported in peer-review journals every month. Application areas are incredibly broad ranging: medical devices, filtration, electronics, composites, energy generation and storage, sensing, acoustics and more. Despite the clear potential for nanofibres to be used in each of these industries, the uptake in terms of the number of commercialised products that utilize electrospun nanofibre remains very limited, with air filtration and lithium-ion batteries being the only sectors in which they are used extensively.

It is clear that the nanofibre industry is growing, but remains hard to define and is growing in a disparate manner. A growing range of innovative applications are being discovered and developed, responding to the trend of our technologies, devices and consumer goods getting smaller; coupled with humanities relentless quest for improvement. We are in an age where we continually explore new properties of materials, especially at the nano-scale. The potential to take the vast array of non-woven textiles to the nano-scale is an intriguing prospect and a strong commercial opportunity in diverse sectors.

One reason for the lack of commercialisation of electrospun fibres is the small scale at which nanofibres are produced using the conventional electrospinning method. In recent years, a number of companies have attempted to address the problem of nanofibre production rates and have developed new methods, adapted from conventional electrospinning, which are capable of significantly faster production than methods previously reported within academia. With these new technological advancements, the potential for the use of electrospun nanofibre in industrial applications has become more achievable and there are a growing number of companies being formed to develop an industry for nanofibre use.

Revolution Fibres has created lab, pilot and industrial-scale electrospinning machines (using its proprietary Sonic Electrospinning Technology™) that have the flexibility and capacity to produce commercial quantities of nanofibre. Recognized as New Zealand's Most Innovative Business (NZ Innovation Awards 2012 Supreme Winner) and with strong engineering and scientific acumen (NZ Engineering Excellence Awards 2012), Revolution Fibres has unique expertise and production capacity, and is well-placed to exploit nanofibre technology and develop high value applications within key export markets.

2 BUILDING THE NANOFIBRE REVOLUTION

The creation and use of nanofibres began in the air filtration industry dating back to the 1930's and continues to the present day. It is a fascinating story of a "forgotten" technology riding the wave of "nanotechnology" and becoming rediscovered in research circles. Now, nanofibre is one of the fastest-growing and most widely adopted form of nanotechnology [1]. As modern technologies seek higher performance and smaller lightweight devices, textiles must follow suit. Nanofibre is a remarkably diverse textile technology, with many materials a possibility.

To be commercially viable, the electrospinning process must be able to produce nanofibre at large enough volume and for a cheap enough cost to be commercially viable when competing with existing alternative technologies or products. Nanofibre is borne out of the centuries-old, very competitive and cost-centric textiles market. In order to compete with existing textiles (and specialty films), nanofibres must offer distinct performance or production advantages such as:

- Improvements in surface area, porosity and reduced thickness and/or weight
- Use of materials and functional additives that would not withstand traditional fibre making techniques (e.g. high heat, high pressure)
- Textiles or membranes small enough to be used in miniaturised devices (e.g. electronics, implantable medical devices etc.)

Currently, the nanofibre industry is a fledgling "technology push" market where hundreds of academic papers per annum are published, many exploring or referencing commercial applications. The main contributing factor to this technology push is the fact that electrospinning at the lab scale is very easy compared with most fibre manufacturing techniques, and most nanotechnologies. Conventional needle based electrospinning is a cheap, achievable "entry" into nanotechnology. Unfortunately, needle-based electrospinning rarely translates into commercial scale electrospinning, so most research has to be re-configured to be commercially viable.

In most cases the ability to produce nanofibre is not enough. For commercial-scale electrospinning companies, the identification of the appropriate applications is critical to their sustainability as a business.

Nanofibre alone is not a product. It is a platform technology that requires adaptation and customization to fit a wide variety of uses such as filtration, skin health, composites, acoustics in building materials and electronics, biotech and energy. The requirements of these sectors are vastly different, and this presents a challenge for nanofibre manufacturers. In response, Revolution Fibres has developed Nanofibre Customisation Services designed to help nanofibre get out of the laboratory and into the marketplace. In this example, Revolution Fibres work directly with Clients on nanofibre product development from idea generation through to large-scale manufacture.

2.1 Building a market for nanofibre production

Although the innovation and market growth signs are very encouraging (CAGR 38.36% [1]), it is still not clear what products or services the nanofibre market entails. The current state of the market sees early adopters of the technology, bar the filtration industry, primarily selling electrospinning machines, rather than nanofibre products. This then puts the onus on end users to become producers, or researchers to become manufacturers.

A novel nanofibre-based technology can be scaled-up by a commercial electrospinning company, but without an engaged industrial client requesting the technology the developers are relying on finding a suitable customer, and bearing the cost of commercialisation and sales, in markets not suited to their skill-set. Furthermore, end users are not readily willing to invest in the as-yet commercially unproven technology without having had any previous involvement in its design or development.

The more preferred method for the commercialisation of a new nanofibre product is therefore one of collaborative development from an early stage. Early engagement between a nanofibre manufacturer and an industrial client who has a real need for nanofibres (whether for performance enhancement in their product or market differentiation) is critical. By involving the end customer from an early stage, the nanofibre can be tailored to the clients' specific requirements, which increases the chances of it providing significant benefits to their product or business. Furthermore developing the product with a manufacturer rather than a research institute can identify the commercial problems earlier, and lead to earlier prototyping and pilot scale production.

Research activities and direction is also fragmented, with far too much duplication across the world. Researchers too can contribute to a coordinated effort to bring nanofibres closer to commercial reality, by engaging with manufacturers and contributing to a pool of research where each party has specific, complementary R&D objectives towards a larger commercial goal.

2.2 Involving a nanofibre manufacturer in research and development

Often companies or academic groups will conduct research and development on a new nanofibre-based technology, using laboratory apparatus, to a point where they have proven the concept and are ready to scale up, only then engaging with a manufacturer. Due to the differences in spinning technology between laboratory-scale and commercial scale electrospinning apparatus, there is often a significant amount of additional development required to scale up the technology, sometimes requiring changing materials completely. This introduces additional costs and delays, which could be avoided by including a commercial manufacturer in discussions and development activities much earlier in the project, before the process is optimised.

Another similar trend is for researchers to "spin out" their nanofibre research into new commercial ventures. While this is exactly what the technology requires, quite often the spinout company decides to become a manufacturer and has to then devote huge resources, new infrastructure and different skill-sets to produce their invention. In some cases it could be faster and cheaper (and better use of investment dollars) to sub-contract the manufacture of their nanofibre invention in order to devote their time and resources on the (not-insignificant) cost of commercialisation. This will reduce start up costs, allow for prototyping and pilot-scale production for samples, and bring new expertise into the venture.

Clearly this is a technology push market, with the rate of innovation (or invention) far surpassing the rate of commercialisation. Revolution Fibres believe product development and manufacture go hand-in-hand. Who better to design your product than a manufacturer of the technology?

3 TURNING NANOFIBRE INTO PRODUCTS

The main markets for polymer nanofibres are air and water filtration, medical devices, composites, batteries and textiles. Polymeric nanofibres account for the main bulk of the current revenues for nanofibres, finding applications across a number of sectors. Although there are also many applications in which inorganic nanofibres have been shown to be of value for example in high temperature filtration applications. Carbon nanofibres are also beginning to find application across a raft of industries including electronics (heat management, EMI shielding, conductors), composites (polymers, resins, glass, ceramics, plastics), energy (batteries, catalysts and fuel cells) and medicine and life sciences (drug delivery, tissue engineering, implants). Carbon nanofibres represent the fastest growing market for nanofibres, especially in Li-Ion battery applications.

Revolution Fibres has developed and commercialised a number of electrospun nanofibre products, both with and without industrial clients involved, which are discussed below as notable examples of nanofibre-based products and technologies currently being commercialised.

3.1 Air Filtration

Nanofibre air filters have been on the market for a number of years. Nanofibres are particularly effective at stopping particles smaller than 0.3 µm with minimal impact on pressure drop. They can adsorb volatile organic compounds (VOCs), microorganisms, allergens, and other pollutants (e.g., tobacco smoke). With the continual rise in air pollution and the IARC's recent classification of air particulates below 2.5 micron as "probable carcinogens", the demand for high efficiency filtration for buildings and personal use shows no signs of abating.

The next phase of growth is in functional, "intelligent" filters that selectively capture pollutants of concern (VOC's, microbes and viruses, heavy metals, etc) using active ingredients. Examples of functional additives include nanoparticles (silver, platinum), metal-organic frameworks and bioactives. An example of this is Seta™ air filtration, developed for a home ventilation company, which is a range of air filtration products that incorporate a fine web of electrospun nanofibre loaded with antimicrobial manuka extract. The same technology is now being explored in personal respirators (facemasks) and as anti-allergy bedding materials, for example pillow liners and mattress protectors, under the brand Nanodream™.

3.2 Nanofibres in composite applications

The composites industry, particularly carbon fibre, continues to experience rapid growth internationally as industries strive for stronger, lighter, and more energy efficient materials. The benefits of fibre reinforced polymer composites are well known and their use has become commonplace in high-tech applications requiring low weight as well as high strength, high stiffness and corrosion resistance. Despite these attributes, fibre reinforced composites generally suffer from poor impact resistance, poor fracture toughness and poor delamination strength. This is particularly the case when brittle thermosetting matrix resins are used.

Lightweight veils made from nanofibres can be used as an alternative to currently-used composite toughening methods such as nanoparticles. Electrospun thermoplastic nanofibre interleaving veils have been shown to improve the compression after impact (CAI), delamination resistance and the Mode I and Mode II interlaminar fracture toughness of composites [2]. Nanofibre veils have also been shown to improve the fatigue resistance and vibration-damping properties of fibre reinforced composite materials.

The first commercial electrospun nanofibre product aimed at composites reinforcement is Revolution Fibres' Xantulayr™, lightweight nanofibre veil that can be easily incorporated between the carbon fibre layers of a composite structure. During curing, the resin infiltrates through the nanofibre veil and the result is a composite with increased impact damage resistance and fracture toughness without additional weight. The first products to make use of Xantulayr™ are a range of high performance fishing rods made by Kilwell and Synit, exported from New Zealand. In their testing of the rods, the presence of Xantulayr™ increased the breaking load of the rods by 100%.

3.3 Nanofibre Acoustic Applications

Sound control is a growing concern in many industries around the globe. Ambient sound can be both distracting and discomforting at excessive levels. Conventional methods of sound control including foams and fabrics have been used to date to absorb, reflect and diffuse sound to a certain degree. However, as our electronic devices, buildings and transportation get slimmer and lighter our needs for hearing protection from environmental / industrial noise, or improved acoustic performance, increase. The challenge for traditional acoustic layers such as foams and various fibrous batts, is to increase performance whilst becoming smaller, lighter and less dense.

Phonix™ acoustic products, developed by Revolution Fibres Ltd, have been found to increase the sound absorbency of existing acoustic materials such as foams and non-wovens. Using the nanofibrous Phonix™ material, the furniture manufacturer Finewood Furniture has developed the Return Focus Pod, a sound absorbing office cubicle for reducing noise pollution in open-plan offices. This product is now sold internationally through Haworth Ltd.

In addition, Phonix™ nanofibre technology has been shown to reduce the unwanted high frequency noise in sound recording and playback in audio devices.

3.4 Medical and Skincare Applications

Nanofibres are uniquely suited to many medical applications due to their structure, which closely mimics that of the extracellular matrix of many of the tissues in our body. Electrospinning allows for a wide variety of natural or synthetic polymers, including many FDA-approved materials, to be spun into nanofibre; as well as for functional additives, such as antimicrobials or growth factors, to be incorporated.

The use of nanofibres in tissue engineering remains in its infancy, but there can be no doubt that this is a fast growing market and it will require suitable scaffold materials as it develops. Another medical field well suited to the use of nanofibre is wound care. There are a number of companies producing nanofibre based wound dressings to exploit the advantages of nanofibres.

Revolution Fibres, too, has developed nanofibre dressings, aimed at the cosmetics and natural health markets. The actiVLayr™ skin delivery platform is a water soluble marine collagen fibre patch that can be loaded with a wide range of plant and fruit extracts that are clinically proven to improve skin elasticity, moisture retention and reduce the appearance of wrinkles and sun spots. actiVLayr® Anti-aging patches and Skin Repair dressings are examples of the myriad of potential products using nanofibres as the delivery platform. By adjusting the extract types (grapes, kiwi, blackcurrant, seaweed, etc), actiVLayr® can target various skin appearances/benefits.

3.5 Nanofibres for Sensing Applications

Sensing is another area where electrospun nanofibre technologies show great promise. Their high surface area and porosity allow for exceptional interaction with their environment (liquid or gas), which means that, with the appropriate functionalization, they are able to react with their target substance with great sensitivity. This natural fit between the inherent high surface area of electrospun nanofibre and the requirements for a sensing material, along with ability to produce nanofibres from a wide range of materials and incorporate a variety of functional additives means that they can be applied in a multitude of sensing devices. Therefore the commercialisation potential is significant, provided the nanofibres can be integrated into the devices in a cost effective manner.

For many sensing applications, biomedical diagnostics in particular, functionalization of the substrate with the probe material plays a vital role as it supports/enhances the interaction between the probe and the target substance. In a promising R&D collaboration, KODE Biotech Ltd (New Zealand) has partnered with Revolution Fibres to combinine their unique biofunctionalisation technique with mass-produced electrospun nanofibre.

Initial trials of Koded Nano-Textiles in various immunological biosensing assays showed that nanofibres have outstanding specificity and sensitivity compared with previously modified materials such as cellulose papers. This demonstrates the potential to revolutionize diagnostic (and environmental testing) kits worldwide – making them simple to use, simple to manufacture and easy to interpret with clear words and graphics (through inkjet or other printing methods) on a high definition substrate – reducing the risk of misdiagnosis and misinterpretation.

Furthermore, Revolution Fibres is perfecting a range of post-treatment steps to incorporate conductive polymers into its range of nano-textiles. Having successfully incorporated PEDOT-based conductive solutions into a range of nanofibre fabrics, the potential of creating ultra-thin, high surface area conducting textiles is being realised, and Revolution Fibres is looking for commercial partners to refine this technology into finished components or products.

4 CONCLUSION

Over the last fifteen years electrospinning has received a great deal of attention from researchers and as a result, our understanding of the process and applications of nanofibre has developed dramatically. Now the technology is maturing, it is increasingly progressing beyond the laboratory and into the industrial setting.

Revolution Fibres has commercialized products with various clients in the areas of filtration, skin health, composites, acoustics, and biotech. The requirements of these sectors are vastly different, and Revolution Fibres has responded through its Nanofibre Customization Services program designed to help nanofibre get out of the laboratory and into the marketplace.

Using its proprietary Sonic Electrospinning Technology™, Revolution Fibres produces commercial quantities of nanofibre. Revolution Fibres has unique engineering and scientific expertise in advanced materials, and a flexible business model that accommodates co-development of superior products; and is well-placed to exploit nanofibre technology in high-value applications through partnerships across a broad range of industries worldwide.

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