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THE UNIVERSAL APPLICATIONS OF MICROTUBES AND MICROTUBE COMPOSITES

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ABSTRACT

Microtubes, are a basic component for a myriad of potential products. They are very small tubes (hundreds can fit in a human hair) that can be made from practically any material. Tubes larger than 1 micron diameter can be made with any cross-sectional shape desired. The significance of microtubes and microtube composites is that they provide the opportunity to miniaturize (even to the nanoscale) numerous products and devices that are currently in existence as well as allowing the fabrication of products that have to date been impossible to produce.

INTRODUCTION

The world is becoming smaller each day. Not just in the field of transportation but more importantly in the field of miniaturization. This is probably most evident in the electronics field with each new generation of integrated circuits, i.e., from integrated circuits to... large scale integration to...very large scale integration to... ultra large scale integration to...? These advances have had a dramatic effect on almost every aspect of modern civilization. However, there are currently many other areas, such as: micromotors, sensors, detectors, microrefrigerators, and scanning tunneling microscopes (STM) where miniaturization is also playing a crucial role.

In many miniaturization applications, there is a need for micro tubing for uses such as: connecting parts, component cooling, sensors, and as probes, to name a few. If the proper micro tubing were available, numerous components and systems could be miniaturized and others could be made more efficient. In addition, many components and systems not currently in existence could become a reality.

Commercially, tubing is extruded, drawn or pultruded, which limits the types of materials that can be used for ultra-small tubes as well as their ultimate internal diameters. As a result, ceramic tubes are currently available only as small as 1mm I.D., copper tubing is available as small as 0.05 mm I.D., polyimide polymer tubing is available as small as 80 microns I.D. and quartz tubing is drawn down as small as 2 microns I.D. This means that quartz is the only tubing available that is less than 10 microns in internal diameter. This quartz tubing is used principally for chromatographic applications. Thus, until the availability of microtubes, only quartz tubing has been available in micron dimensions and no tubing has existed with sub micron internal dimensions.

DESCRIPTION OF MICROTUBES

In contrast to tubing currently on the market, microtubes can be made from practically any material with precisely controlled composition down to internal diameters less than 5 microns. (There is no upper internal diameter limit.) In addition, for materials that can survive temperatures greater than 400^{o} C, tubes can theoretically be made as small as 5 nanometers. To date, tubes have been made from metals (copper, nickel, aluminum, gold, platinum, silver) , ceramics (silicon carbide, carbon, silicon nitride, sapphire), glasses (silica), polymers (teflon), alloys (stainless steel) and layered combinations (carbon/ nickel, silver/sapphire) in sizes from 0.5 - 300 microns. (By comparison a human hair has a diameter of ~ 100 microns.) Some scanning electron microscope (SEM) micrographs of these tubes can be seen in Figure 1.

RINSE WATER RECOVERY SYSTEM

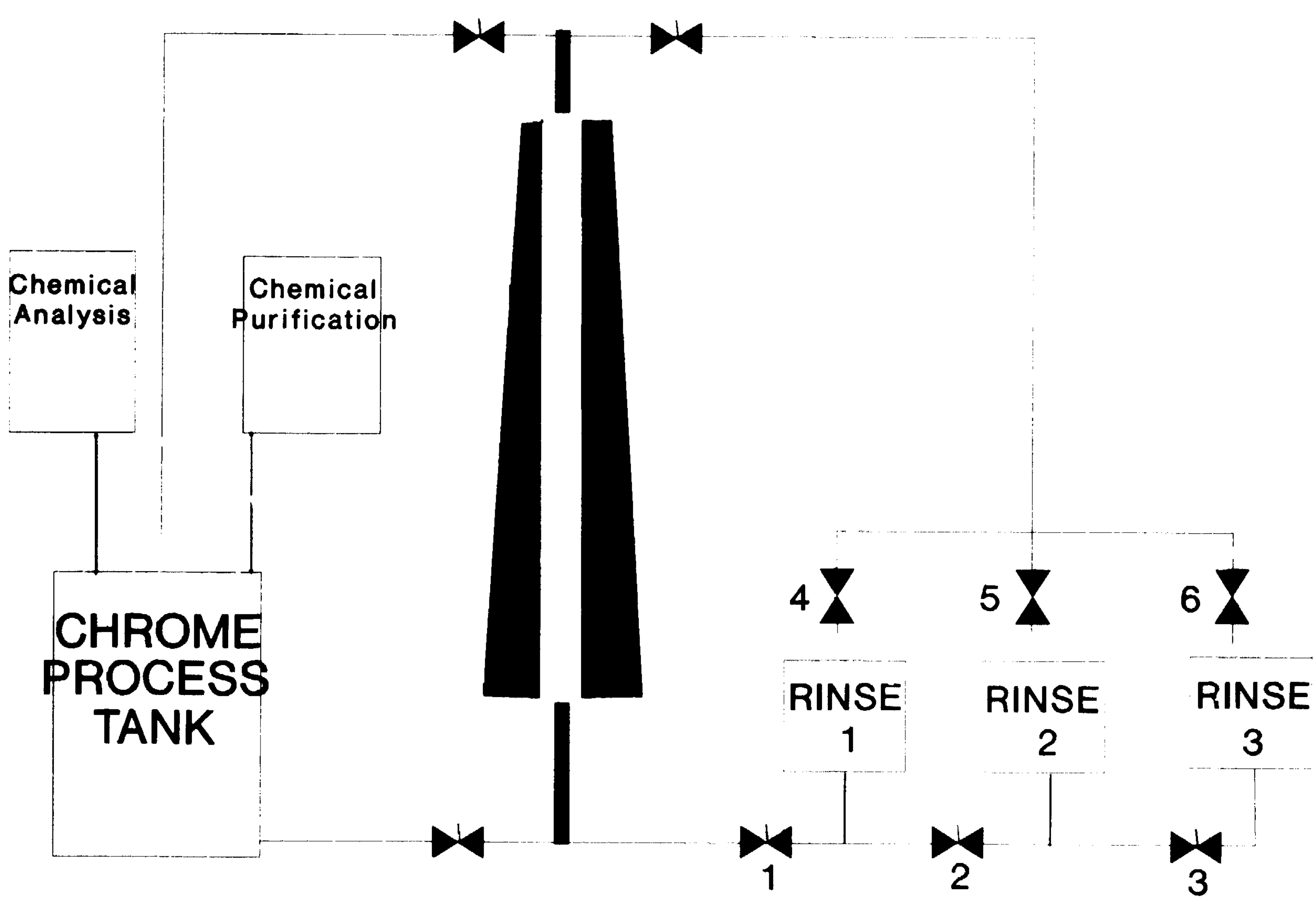
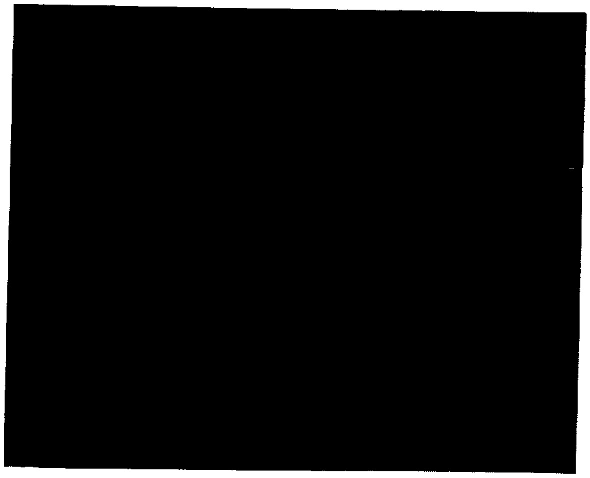
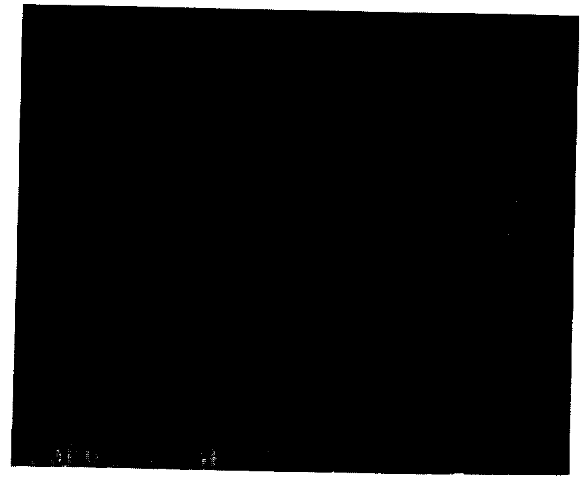


FIG. 3



(a)



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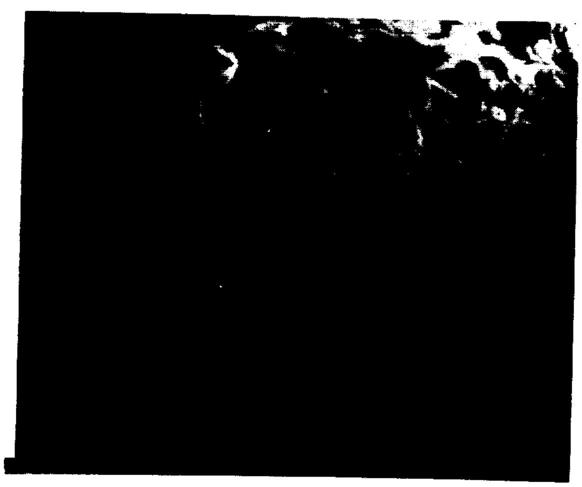
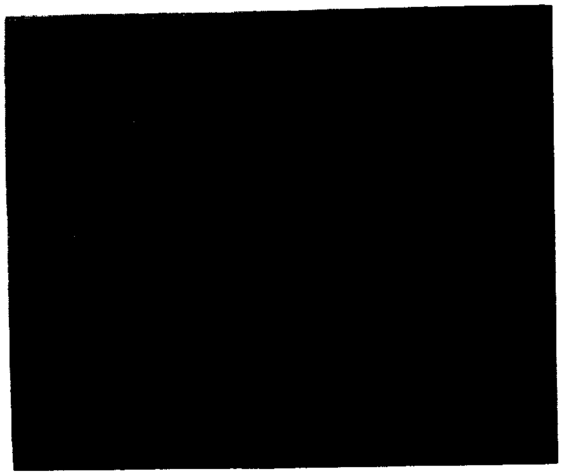


c)

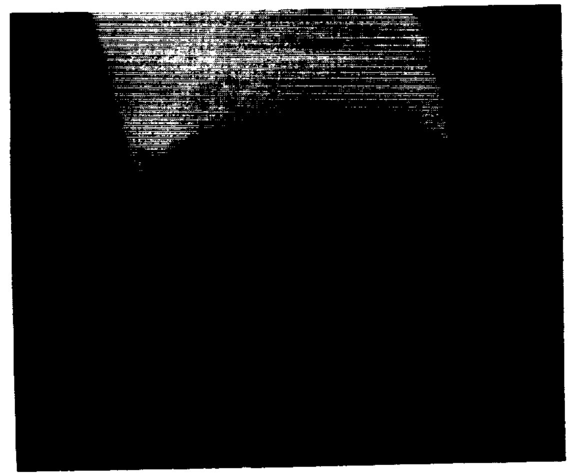
(d)

Figure 1. Examples of microtubes. (a) 10 micron silicon carbide tubes. (b) 10 micron nickel tubes. (c) 26 micron silicon nitride tube. (d) 0.6 micron quartz tube.

Since the process does not involve pultrusion, extrusion or drawing but rather a fugitive tube forming process, cross-sectional shapes as well as wall thickness can be very accurately controlled. A myriad of shapes have already been made as seen in Figure 2. These micrographs should be sufficient to demonstrate that practically any shape imagined can be fabricated. As seen in Figure 2, the wall thickness on the tubes can be held very uniform around the tube. It is also possible to control the wall thickness along the length of the individual tubes as well as among the tubes in a batch. To date, free-standing tubes with some mechanical strength have been made with wall thicknesses as small as 0.01 microns. (Figure 3) There is no upper limit to wall thickness as will be discussed below.



(a)



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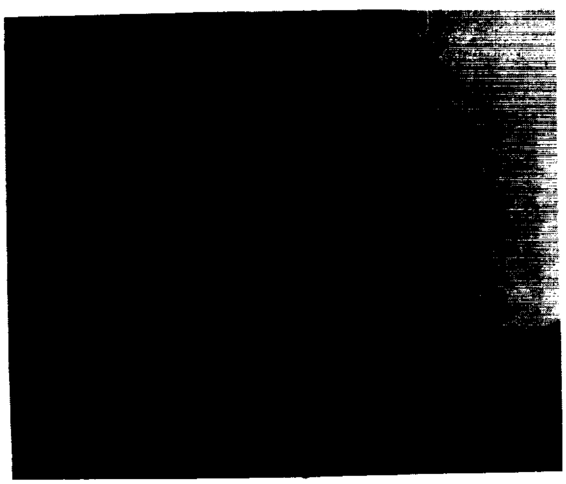


(c)

(d)

Figure 2. Above 1 micron inside diameter tubes can be made in any cross-sectional shape such as (a) 17 micron star, (b) 9 X 34 micron oval, (c) 59 micron smile, and a 45 micron trilobal shape.

The maximum length that these fibers can be made has yet to be determined because it depends on many variables, such as, type of tube material, composition of sacrificial tube forming material, degree of porosity in the wall, etc. It is possible that with a porous wall there is no limitation in length. For a non-porous wall the maximum length would probably be measured in feet with there being a direct relationship between the tube I.D. and the maximum possible length. However, for most applications conceived to date, the length need only be measured in inches. If one does a quick calculation it is apparent that even "short" tubes have a tremendous aspect ratio. For instance, a one inch long 10 micron I.D. Tube has an aspect ratio of 2500.

Currently, these tubes have been made by a batch process in the laboratory but the technique is equally suited to a continuous process which would not only be more efficient but in some cases easier. Obviously, a continuous process would reduce the cost which for most materials is already rather low because, unlike other processes, expensive tooling is not needed. For many materials such as quartz, aluminum, copper, etc. the cost is anticipated to be much less than $0.01/ inch. For precious metals such as gold or platinum the cost would be significantly higher due to the cost of the raw materials.

(a)

(b)

Figure 3. Tube can be structurally sound with very thin walls. (a) Unbroken tube. (b) Tube broken to expose interior.

MODIFICATIONS FOR VARIOUS APPLICATIONS

Microtubes can be made free-standing, with wall thickness as small as 0.01 microns, or the walls can be made so thick that the space between the tubes is filled producing a solid monolithic structure with micro channels (Figure 4). These micro channels can be randomly oriented or they can have a predetermined orientation. Any desired orientation or configuration of microtubes can be obtained by a fixturing process. Alternatively, composite materials can be made using a material different than the tube wall as a "matrix" that fills in the space between the tubes. The microtubes imbedded in these monolithic structures form oriented micro channels which like free-standing tubes can contain solids, liquids and gases, as well as to act as conduits for all types of electromagnetic energy. If the tubes are placed in a solid structure they can act as lightweight structural reinforcement similar to that found in bone or wood. The cross-sectional shape of these reinforcement tubes can be tailored to maximize mechanical or other properties.

The interior surface of these tubes can have practically any desired texture and degree of roughness which would be advantageous in many applications. In addition, the interior cr exterior surface of these tubes can be coated with a layer or layers of another material (Figure 5) to form, for instance, a multiple path conductor or a tube for chemical reactions. When the tube is filled with another type of material, for example, it can become a sensor, detector, or an element in an electron multiplier.

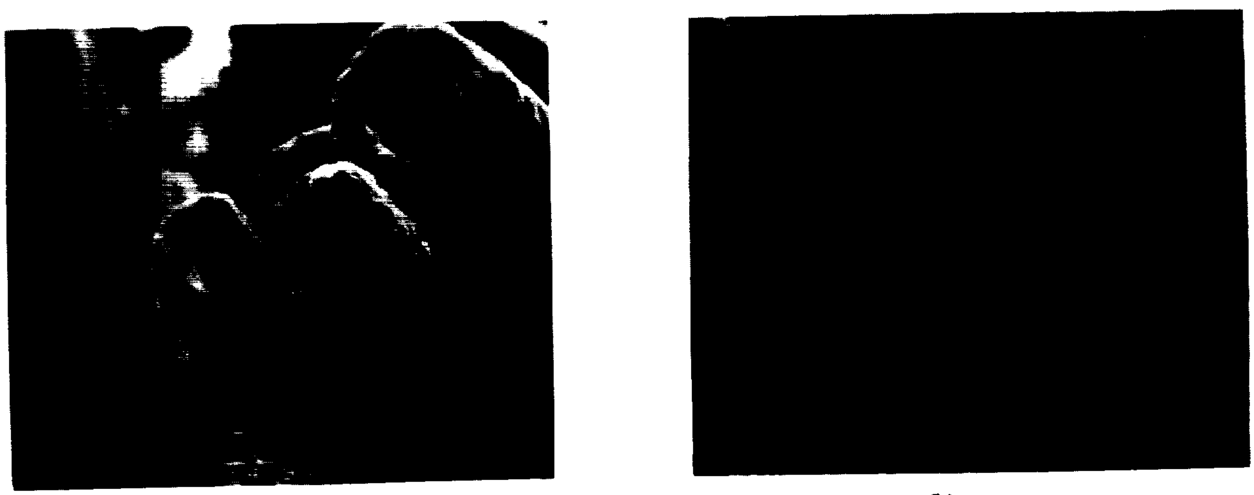
Depending on the application, the walls of microtubes can range from non-porous to extremely porous as seen in Figure 6. In addition the tubes can be made straight, curved or coiled as seen in Figure 7. For many applications it is desirable to be able to interface microtubes with the macro world with a gradual decrease in the internal diameter. This is possible by a tapering process in which the diameter is gradually decreased to micron dimensions. Alternatively the tubes can be interfaced to the macro world through numerous types of manifolding schemes.

APPLICATIONS AND USES

Microtubes appear to have almost universal application in areas as diverse as optics, electronics, medical technology, and microelectromechanical devices. As a result, their specific function depends on the product in which they are applied. Specific applications for microtubes are as diverse as chromatography, encapsulation, heat exchange, injectors, micro-pipettes, dies, composite reinforcement, detectors, micropore filters, insulation,

Figure 4. Solid carbon tube with microchannels.

Figure 5. Sapphire tube with silver liner.



(a) (b)

Figure 6. Examples of porous tube walls. Pores mainly in the sides (a). Pores mainly longitudinal (b).

displays, sensors, optical wave guides, flow control, pinpoint lubrication, micro sponges, heat pipes, microprobes, plumbing for micromotors and refrigerators, arrays for printers and xerography drums, etc. The technology works equally well for high and low temperature materials and all applications that have been conceived to date appear possible at this time.

Figure 7. Example of a curved nickel tube.

SUMMARY

The significance of microtubes and microtube composites is that they can be fabricated inexpensively out of practically any material in a variety of cross-sectional shapes and in diameters orders of magnitude smaller than is now possible. These tubes will provide the opportunity to miniaturize (even to the nanoscale) numerous products and devices that are currently in existence as well as allowing the fabrication of products that have to date been impossible to produce. For example, as electronic circuits become smaller and more compact, there is a greatly increased need for micro-cooling. The solution to this problem currently does not exist. Microtubes can satisfy this need in the form of micro-heat pipes or heat exchangers.

From the above discussion, it has become evident that microtube composites have become "solutions in search of problems" and that future applications will be limited only by mankind's imagination.

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BIOTECHNOLOGY/MEDICAL TECHNOLOGY