Nanocoated Converted Coral Meets High Structural Strength Requirement for Load-Bearing Bone Graft Applications

Current bone graft materials are largely made of natural coral that has been converted to coralline hydroxyapatite [$Ca_{10}(PO_4)_6(OH)_2$] (HAp). From a mechanical and structural perspective, commercial coralline products are associated with two significant problems. One is incomplete conversion of the aragonite (calcium carbonate) to HAp, with the inner core remaining as unconverted $CaCO_3$. This limits control of the biodegradation of the graft because the solubility rates of the two materials differ. Uncontrolled dissolution in the physiologic environment compromises the durability, tissue integration, and ultimately the long-term success of prostheses that are intended to be load-bearing.

A second problem originates in the porosity of the converted material. Although coralline HAp has a favorable macroporous structure consisting of a network of interconnecting channels (150–500 μm in diameter) that allow tissue in-growth (see Figure 1), the spine (interpore solid structure) is laced with a system of very fine interconnecting nano- and micropores (<1 μm in diameter); this microporosity is susceptible to fracture, thus compromising the structural integrity of the graft and precluding its use in direct load-bearing applications.

To overcome these limitations, a recently patented dual-stage conversion technique has been developed by Nanocoatings Pty. Ltd. in Australia. In the first stage, complete conversion of coral to pure HAp is achieved by using a hydrothermal process and excess ammonium monohydrogen phosphate to completely replace the calcium carbonate with calcium phosphate throughout the specimen. In the second stage, a sol-gel-derived HAp nanocoating (70–100 nm) is directly applied to cover the micro- and nanopores within the intrapore material while maintaining the large pores (see Figure 2). This double treatment improves the biaxial strength from 7.6 ± 1.4 MPa of converted coral to 13.3 ± 6.5 MPa of the converted and coated coral.

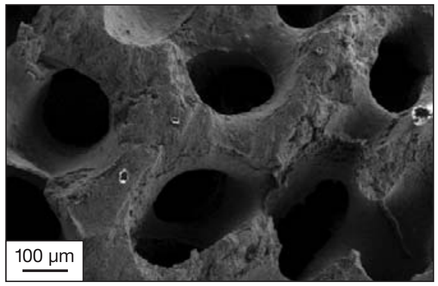

Figure 1. Surface of coral containing interconnected macropores of 150–500 μm.

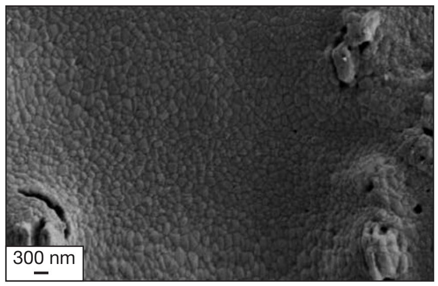

Figure 2. Surface of converted and hydroxyapatite-coated coral. The micro- and nanopores of the converted coral are covered with a sol-gel-derived hydroxyapatite layer.

Pilot studies of the dual-stage conversion procedure have confirmed that samples are completely converted to single-phase HAp. Ultrastructural analysis using scanning electron microscopy has shown that the coating step effectively obliterates the surface nanopore system while leaving the macropore system intact, resulting in increased mechanical strength as compared with commercial products.

Opportunities

Nanocoatings Pty. Ltd. seeks partners to commercialize its novel processes and materials.

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SiGe Graded-Layer Technology Ready to be Incorporated into III–V Optical Interconnect Systems

The ability to gain large economies of scale in silicon computing capability has played a significant role in nearly every major technological advancement over the past four decades. Improvements in Si transistor manufacturing technology have been central to this evolution and have been described by Moore's law, which asserts that the density of transistors doubles about every 18 months. Methods to improve circuit performance have now shifted from feature size reduction alone to the use of materials technologies such as the introduction of copper wiring to reduce metal interconnect delays in integrated circuits. The next step requires the implementation of further materials solutions for enabling high carrier mobility, light emission, light detection, and light routing capabilities on a single chip.

AmberWave Systems Corp. has developed commercial chemical vapor deposition (CVD) techniques for SiGe graded-layer technology that enables lattice constants on Si corresponding to compositions ranging from 0% Ge to 100% Ge. Lattice-mismatch engineering by linear grading technology is the most established method for enabling multimaterial functionality in a variety of semiconductor materials systems. Of these technologies, the SiGe alloy system shows the most promise for allowing a host of lattice constants and materials to be placed on bulk Si while retaining the manufacturing methods that allow silicon-based microelectronics to maintain their low cost.

The SiGe alloy system is said to be a key to the economic integration of high-mobility transistors with optoelectronic interconnect technology. AmberWave Systems' proprietary planarization processes in tandem with novel CVD methods allow the fabrication of ultrasmooth surfaces, which are required for high-yield device fabrication sequences, and minimize the introduction of line defects in the device layers. The key system functionality enhancements are listed in Table I.

Commercialization of strained Si transistors is currently under way. The development of several other possibilities in silicon microsystem technology have been demonstrated:

- SiGe graded-layer technology has been applied to Ge photodetectors on Si, with results demonstrating a 3.5 GHz bandwidth capability and a simulated capability for 7 GHz (10 Gbit/s) application.

Technology Advances provides up-to-date reports of materials developments that show potential to bridge the gap between research innovation and application of advanced materials technologies. If you encounter or are involved with materials research that shows potential for commercialization and would like to present these developments, contact Renée G. Ford, Renford Communications, renford@comcast.net.

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■ Production techniques are being developed to scale SiGe graded-layer technology into high-volume, low-cost substrate manufacturing.

■ Initial demonstrations of III–V compound lasers on Si established with SiGe graded-layer technology have displayed room-temperature, continuous-wave operation with differential quantum efficiency (0.24), and threshold current density (577 A/cm^2) equivalent to III–V compound control lasers.

■ The combination of light-detecting and light-emitting materials for on-chip communications is one of the goals of photonic integration efforts on silicon. GaAs PIN light-emitting diodes and GaAs PIN detector diode pairs with integrated AlGaAs waveguide geometries made with SiGe graded-layer technology have been demonstrated.

Table I: Fundamental Enhancements in Silicon Microsystem Functionality Based on Ge Content

Structure	Ge Content (%)	Key System Functionality Enhancement
Strained Si transistor	15–30	80%–100% electron mobility enhancement
Strained Si transistor	>40	120% hole mobility enhancement
Dual-channel transistor	>50	500% hole mobility enhancement
Ge channel transistor	>70	700% hole mobility enhancement
Photonics on Si	100	Ge detectors on Si; Lasers on Si; Optical links on Si

Opportunities

AmberWave Systems Corp. is interested in engaging in cooperative development programs with partners and licensees of its proprietary SiGe-based platform technologies among which are plans to use its III–V-based photonic devices on Si for a variety of applications.

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New Heating Techniques and Ceramic Crucibles Make Melting and Casting of Metals Microwave-Compatible

Placing a metal fork or aluminum foil in a home microwave oven can cause arcing and electrical damage to the oven. However, by controlling the microwaves to uniformly heat a ceramic crucible containing the metal, the electric field surrounding the metal is sufficiently reduced to avoid arcing. Researchers at Microwave Technology Inc. in Tennessee have developed microwave processes for melting and casting a variety of metals—including aluminum, superalloys, and high-level metal scrap—at melt temperatures well above 2000°C without generating plasma about the metal. Thermally, microwave heating is an efficient process. Heated uniformly, the ceramic crucibles transfer heat to the metal. This minimizes thermal shock when the ceramics are heated and cooled.

An advantage of microwave heating over induction heating is that efficient heating does not require a large single block of metal or molten metal at the bottom of the crucible. The system can readily be used for different metals and crucibles. In addition, microwaves do not require water-cooled coils, which further reduces the possibility of water leaks and contamination.

The researchers' development of nonwetting, microwave-compatible ceramic materials for melting and casting reduces the contamination often found in commercial processes that use molds coated with refractory paints. Painted coatings tend to erode, crack, and flake into the melt, leaving inclusions in the cast metals. The exposed areas of the (typically graphite) crucible can then react with some metals, also adding to the impurity and inclusion content. Inclusions and impurities as well as porosity can lead to stress concentrators in a casting, thereby reducing the strength or aesthetic value. Vacuum processing with microwaves has also been demonstrated, which minimizes reactions, porosity, embrittlement, and cracking. The reduction of the nonwetting inclusions removes much of the porosity. In addition, because of the higher temperatures generated, the viscosity of the metals is reduced, and the metals can be cast to finer dimensions.

The uniform and rapid heating achievable with microwaves is not attainable by induction and other conventional heating processes. Controlled microwave heating permits the use of a wide size range (~2.54–45.7 cm) of refractory crucibles, which are difficult to heat (and cool) conventionally without cracking.

Figure 1. An aluminum ingot (14 cm in diameter; 7.62 cm thick) that has been melted in the microwave furnace.

Rapid cooling of a casting is possible with this technique, since the furnace walls are near room temperature. Rapid cooling to less than half the melting temperature generally minimizes grain growth in the metal, increasing the metal's fracture toughness. Removal of most cast metals upon cooling is relatively easy when the metal does not wet the ceramic as a liquid, so long as the thermal contraction of the metal is greater than that of the ceramic. Removal of a hot solidified metal from the crucible or mold permits forging or very rapid cooling by quenching.

Microwave Technology has set up a large, near-commercial-sized microwave furnace (1.2 m long and 1.2 m in diameter) with the capacity to handle crucibles from 2.54 cm to 45.7 cm. The processing of metal and several types of metal alloys has been demonstrated, including steels, copper, nickel alloys, and aluminum. An Al ingot is shown in Figure 1.

Opportunities

Microwave Technology Inc. welcomes inquiries about collaboration for commercializing their technology. Areas of interest include complex or new alloys, pure metals, molds, and scaling to very large batches or continuous processing.

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