TECHNICAL INSIGHTS

ADVANCED MANUFACTURING

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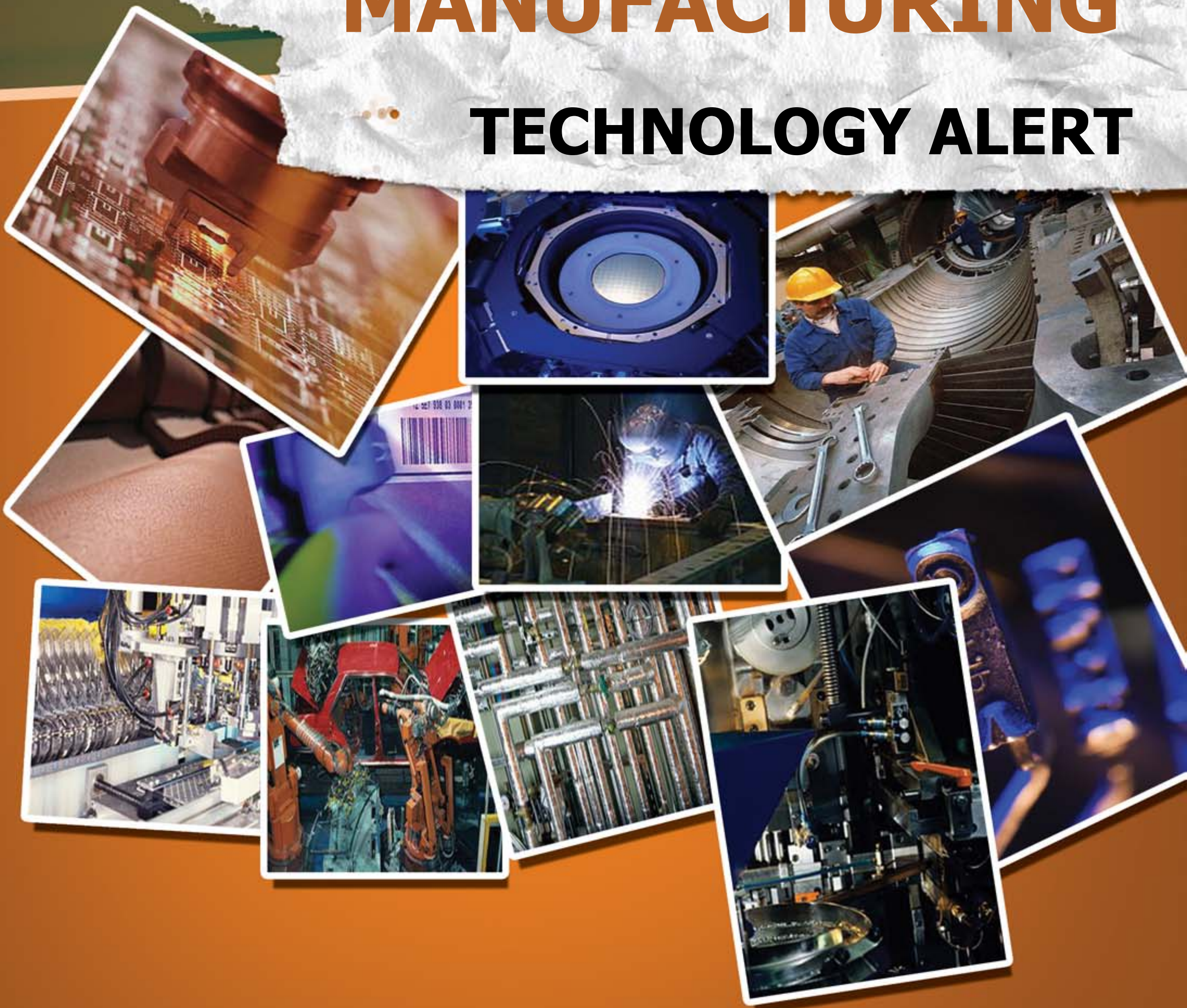

17th April 2015

1. NOVEL PROCESS TO PURIFY CARBON NANOTUBE ARRAYS

For years, scientists have been deliberating about and researching the vast and myriad applications that the discovery of carbon nanotubes has opened up. Possessing exceptional strength and rather unique electrical properties, carbon nanotubes have opportunities in many applications in nanotechnology.

A very important property of carbon nanotubes is its semiconductor nature. Similar to other semiconductors, such as silicon or gallium arsenide, carbon nanotubes can behave like an electronic switch. However, the nanotubes are very small, to the extent that a single carbon nanotube can be called the smallest electronic switch in existence. Interestingly, their semiconductor capabilities can be on par with any other commercially available semiconductors.

Carbon nanotubes are usually aligned in arrays to make a film of carbon nanotube semiconductors. When arranged in this fashion, some part of the film exhibits electrical conductivity like metals. This compromises the semiconductor property of the nanotube film excessively. The implication of this will be that it can no longer be used in any potential electronic application. Eliminating this barrier is crucial for making electronics at the nanoscale.

A research team from the University of Illinois- Urbana Champaign has found a rather simple yet powerful technique to make semiconductor films from carbon nanotubes. According to the head of the research team, an error of even 0.0001% in the film could sabotage the electronic device it is used in.

The researchers explain that the process is relatively less complex, can be scaled up for larger adaptation, and does not require any costly apparatus. They say that two prominent roadblocks existed in making semiconducting material from carbon nanotubes. The first challenge, which was addressed by a decade and a half of research, was to align the nanotubes on thin films uniformly and in good densities.

The second major challenge is to ensure the purity of the semiconductor formed by carbon nanotubes. This requires purging the nanotubes of their metallic characteristics. Although new approaches have been successful in eliminating this 'impurity' in the recent past, these methods bank on expensive equipment. This increases the cost of electronic devices made from these materials. While carbon nanotubes have been considered to replace silicon in future electronics, a costlier purification can serve as a deterrent for commercialization of these technologies in the near future.

The first step of this less expensive process was to bring an arrayed carbon nanotube sheet in contact with a metal sheet. Then, a thin layer of organic material was accumulated on the sheet. Next, a small current was flown through the nanotubes by applying a current across the sheet. The current would easily flow through the metallic tubes as opposed to the other tubes that are semiconductor in nature.

As the current passed through the metallic nanotubes, they heated up slightly and created an occurrence called as "thermal capillary overflow". This occurrence ripped the coating of organic material on top of the tube leaving the metallic nanotubes visible. Using standard equipment and procedures, the visible metallic nanotubes were etched away. Later, the organic coating on the sheet was removed by washing it away. The remainder was a clean sheet of electronic wafer containing a layer of carbon nanotubes with semiconducting abilities, free of any metallic impurities. The researchers later tested these wafers by creating transistor arrays.

Carbon nanotube semiconducting films are a promising replacement for silicon as a less expensive material in nanoelectronics. These films can shrink the size of chips by a large factor and ably deliver performance in nanoscale. This new process contributes to overcoming the challenges for creating stable semiconducting materials from carbon nanotubes; also, it adds value by bringing cost-efficiency to the production process. The scalability of this new process could make carbon nanotubes the successor of silicon in the near future.

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2. INNOVATIVE APPROACH FOR DEVELOPING CARBON NANOTUBES FOR THE AIRCRAFT SECTOR

Composite materials that are employed in aircraft components such as wings and fuselages are usually manufactured in large, industrial-size ovens. In this process, multiple polymer layers are heated using temperatures up to 750 degrees F, and then solidified to form a solid, strong material. This process uses up a large amount of energy—for heating the oven, then the gas around it, and finally, in developing the actual composite.

Researchers from the Massachusetts Institute of Technology (MIT), USA, have developed a novel carbon nanotube (CNT) film that could be heated and solidified into a composite without using large ovens. The researchers have used an electrical power source and wound multiple layers of polymer composite and heated films to help the polymer to solidify. The research team has tested the film on common carbon-fiber materials that are employed in aircraft components. The results from the test have shown that the film solidifies into a composite that is as strong as the ones manufactured in conventional ovens though it uses only one percent of the energy required by conventional processes. The technique has been named the out-of-oven approach and is said to offer a more direct, energy-saving method for effectively manufacturing any industrial composite. The carbon nanotube film developed using this approach is also said to be significantly light in terms of weight and diameter.

The researchers investigated the film's potential to fuse two types of aerospace-grade composites typically used in aircraft wings and fuselages. Normally, the material, composed of about 16 layers, is solidified, or cross-linked, in a high-temperature industrial oven. However, using the novel approach, the researchers manufactured a CNT film about the size of a Post-It note, and placed the film over a square of Cycom 5320-1. Then, they connected electrodes to the film to apply current for heating both the film and the underlying polymer in the composite layers of Cycom. From the experiments it has been found that, using the innovative approach, only one-hundredth of the energy expended by the conventional approach is required to cure the composite. Both methods generated composites with similar properties, such as, cross-linking density. The research team is currently working on testing the CNT films to make them feasible for use in various industrial sectors.

Some of the advantages of this approach are that it significantly reduces the energy consumption and develops lightweight components for different industrial sectors, which would in turn help in increasing energy efficiency.

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3. THREE-DIMENSIONAL ANALYSIS OF OBJECTS USING ROBOTIC SYSTEMS

In addition to industrial applications, such as material handling, welding, assembly, dispensing, and so on, advancements in robots are enabling expanded applications in areas such as geological materials. In this vein, researchers at the Georgia Institute of Technology, USA, have developed a robotic system for simulating and analyzing the chemical reactions of early Earth on the surface of rocks.

In an experiment conducted by the researchers, a part of the product with irregular shape was selected for analysis using a three-dimensional (3D) camera that was fitted to a robotic arm that mapped the 3D coordinates of the sample object's surface. The robotic arm was programmed in a way that it was used to punch the sample using an acupuncture needle in order to collect a small amount of the material by poking.

According to the researchers, this robotic system is capable of analyzing the 3D mass spectrometry of native surfaces. The National Science Foundation (NSF) Major Research Instrumentation Program (MRI) grant and the National Science Foundation (NSF) and NASA Astrobiology Program, under the NSF Center for Chemical Evolution, are some of the key programs through which this research has been supported.

To further assess the capability of the robotic system in testing 3D objects, the researchers imprinted ink patterns on the surfaces of polystyrene spheres. The robotic arm was then employed to model the surfaces, probe specific regions, and analyze whether the samples collected were sufficient for mass spectrometry analysis. Through these operations, the researchers were able to detect links of various colors and create a 3D image of the object with sufficient sensitivity for establishing the proof of their principle.

According to the researchers, the initial findings of this research have marked a significant development in the employment of robots for 3D surface experiments on geological material. Currently, the researchers are working on repeatability and improving the accuracy of robots to achieve capabilities that would have numerous potential applications in the biomedical field. To achieve such capabilities, a new mass spectrometer having a higher resolution than the one employed in the initial stages of the research has been adopted. The resaerchers are also planning to replicate the early earth chemistry on rocks and to analyze the reaction products with the novel robotic sampling system.

The advantage of this robotic system is its capability to analyze irregularly shaped objects in a 3D format, which can be used for a wide range of diverse applications.

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4. PATENT ANALYSIS OF LASER MICROMACHINING PROCESS

Laser micromachining is a process in which a focused optical light beam is employed for selectively removing the materials from a substrate, thereby creating a desired feature on the surface or internal part of the substrate. Laser micromachining is a non-contact type of process, but it has a significantly high spatial limitation. Compared to the other mechanical machining processes, the amount of heat generated in the work piece is significantly low. This process also relies on linear optical absorption and plasma formation mechanisms.

The key advantage of laser micromachining when compared to conventional machining processes is that, in conventional processes, it not possible to create micro-sized structures since the linear absorption of the materials often leads to increased heat deposition. The high heat deposition also results in the formation of micro cracks and small damages to the surrounding area of the work piece, which are not avoidable. Another key advantage of this process is that the laser micromachining systems are highly flexible.

From the patents presented in Exhibit 1, it can be seen that research has been carried out to improve various components and parts that are being used in laser micromachining process, such as a Laser micro-machining system with post-scan lens deflection (US 8288684 B2), assigned to Electro Scientific Industries, Inc. The patents also reflect work on applications for laser micro-machining such as Laser micromachining optical elements in a substrate

(WO 2013048781 A3), assigned to Rambus, Inc., which pertains to the formation of optical elements with small increments in average density in a substrate via laser micromachining using a variable aperture and a set of pattern masks

Title	Publication Date/Publication Number	Assignee	Inventor	Abstract
Coaxial water jet device used for laser micro machining of thin-walled tube	July 24, 2013/ CN 103212845 A	Machinery Co., Ltd.	Wei Zhiling, Ning Jun, Xiafa Ping, Ma Xiuyun	The invention discloses a coaxial water jet device used for laser micro machining of a thin-walled tube. The device comprises a laser generator, a focusing mirror, a protective mirror, a nozzle, a water supply unit and a high pressure auxiliary gas unit, wherein the focusing mirror is used for focusing laser beams sent out from the laser generator; the laser beams penetrating through the focusing mirror are further focused and straightened by the protective mirror, and the protective mirror is coupled with an inner wall of the device in a sealing manner so as to prevent water vapor from entering the device; the nozzle is used for outputting the focused and straightened laser beams for machining; the water supply unit supplies cooling water coaxial with the laser beams outside the nozzle to assist the machining; and the high pressure auxiliary gas unit provides high pressure auxiliary gas coaxial with the laser beams in the nozzle through a gas inlet communicated with the nozzle, and the auxiliary gas is sprayed out from the nozzle so as to prevent the water vapor from entering the nozzle.
Laser micromachining optical elements in a substrate	May 23, 2013/ WO 2013048781 A3	Rambus Inc.	Timothy A. Mccollum, Fumitomo Hide, Ian Hardcastle	Optical elements with small increments in average density are formed in a substrate by laser micromachining using a variable aperture and a pattern mask set of pattern masks each having of shape-defining elements whose density differs among the pattern masks in first density increments. A laser light beam passes through a combined mask formed by the variable aperture and one pattern mask selected from the pattern mask set. The variable aperture controls beam size and the pattern mask spatially modulates its intensity. A focusing element focuses light from the combined mask on a small averaging region of the substrate. Different combinations of the size of the aperture mask and the selected pattern mask are used in combination at respective averaging regions of the substrate. The resulting average densities of the optical elements vary among the averaging regions in increments that are small compared to the first density increments.
Optical component cleanliness and debris management in laser micromachining applications	November 27, 2012/ US 8320424 B2	Electro Scientific Industries, Inc.	Bryan C. Bolt, David M. Hemenway, Mark Kosmowski, A. Grey Lerner, Brady E. Nilsen, Richard Pope	Preferred embodiments of a purge gas port, laser beam attenuating input window, and laser shutter constitute subsystems of a UV laser optical system in which a laser beam is completely enclosed to reduce contamination of the optical system components. Purge gas is injected through multiple locations in a beam tube assembly to ensure that the optical component surfaces sensitive to contamination are in the flow path of the purge gas. The input window functions as a fixed level attenuator to limit photopolymerization of airborne molecules and particles. Periodically rotating optical elements asymmetrically in their holders reduces burn damage to the optics.
Laser micro-machining system with post-scan lens deflection	October 16, 2012/ US 8288684 B2	Electro Scientific Industries, Inc.	Mehmet E. Alpay, Jeffrey Howerton, Patrick Leonard, Michael Nashner, David McKeever	A laser micro-machining system includes a laser source positioned to direct a laser pulse through a scan lens to a work piece mounted on a work surface and a mirror positioned between the scan lens and the work piece and tilted with respect to the work surface to reflect the laser pulse toward the work piece. The mirror can be indexed to a number of positions so that only portions of the mirror are used for a number of processing steps, extending the life of the mirror.

Title	Publication Date/Publication Number	Assignee	Inventor	Abstract
Reducing back-reflection in laser micromachining systems	October 11, 2012/ WO 2012082930 A3	Electro Scientific Industries, Inc.	Mehmet E. Alpay, Guangyu LI	Systems and methods reduce or prevent back-reflections in a laser processing system. A system includes a laser source to generate an incident laser beam, a laser beam output to direct the incident laser beam toward a work surface along a beam path, and a spatial filter. The system further includes a beam expander to expand a diameter of the incident laser beam received through the spatial filter, and a scan lens to focus the expanded incident laser beam at a target location on a work surface. A reflected laser beam from the work surface returns through the scan lens to the beam expander, which reduces a diameter of the reflected beam and increases a divergence angle of the reflected laser beam. The spatial filter blocks a portion of the diverging reflected laser beam from passing through the aperture and returning to the laser beam output.
Method for laser micromachining	September 11, 2012/ US 8263901 B2	Oerlikon Solar Ag, Truebbach	Robert Bann, Neil Sykes	A method of laser micro-machining, by means of a laser, a work piece (**31**) of the type described comprising the steps of: locating the workpiece on a carrier forming a part of a transport system whereby the carrier can be displaced along a path (P) parallel to an X-axis of the workpiece, a Y-axis lying transverse the path, and a Z-axis lying transverse the path; focusing an image generated by means of an output beam from the laser at a working datum position (A) defined relative to the path which path is established by means of the transport system to traverse the first datum position; a plane defined by the X- and Y-Axis lying substantially perpendicular to the output beam; and displacing the workpiece along the path by way of the transport system so as to enable the work-piece to be subject to micro-machining by way of the laser characterized by the steps of: maintaining distance between the datum position and a current first surface position of the work-piece in the vicinity of the datum position; and varying the working datum position to accord with local variations in thickness of the workpiece so that the working datum position is maintained at a fixed distance relative to a surface of the workpiece apparatus therefor.
Polymer tubing laser micromachining	February 16, 2012/ WO 2012021748 A1	Raydiance, Inc.	Tim Booth, David Gaudiosi, Michael Greenberg, Gordon Masor, Michael Mielke	An apparatus for athermal ablation of a workpiece. The apparatus may include a laser device to direct a laser beam at the workpiece to remove a plurality of sections from the workpiece by athermal ablation. The removal may occur in a plurality of discrete motions that cause the laser beam to trace along outer perimeters of the sections in a specific order maintaining mechanical stability of the plurality of sections. The apparatus may further include a process gas nozzle to deliver process gas coaxially with the laser beam to clear debris and cool the workpiece, and a workpiece holder to hold and maneuver the workpiece during the removal of the plurality of sections.

Title	Publication Date/Publication Number	Assignee	Inventor	Abstract
Laser micromachining and methods of same	February 22, 2011/ US 7893386 B2	Hewlett-Packard Development Company, L.P.	Charles Otis, Mehrgan Khavari, Jeffrey R. Pollard, Mark C. Huth	The described embodiments relate to laser micromachining a substrate. One exemplary method includes forming a feature into a substrate, at least in part, by directing a laser beam at the substrate. During at least a portion of said forming, the method includes supplying liquid to at least a first region of the feature along a first liquid supply path and supplying liquid to at least a second different region of the feature along at least a second liquid supply path.
Laser micromachining with tailored bursts of short laser pulses	January 13, 2011/ WO 2010111089 A3	Electro Scientific Industries, Inc.	Yunlong Sun	A series of laser pulse bundles or bursts are used for micromachining target structures. Each burst includes short laser pulses with temporal pulse widths that are less than approximately 1 nanosecond. A laser micromachining method includes generating a burst of laser pulses and adjusting an envelope of the burst of laser pulses for processing target locations. The method includes adjusting the burst envelope by selectively adjusting one or more first laser pulses within the burst to a first amplitude based on processing characteristics of a first feature at a target location, and selectively adjusting one or more second laser pulses within the burst to a second amplitude based on processing characteristics of a second feature at the target location. The method further includes directing the amplitude adjusted burst of laser pulses to the target location.
Dual pulsed beam laser micromachining method	November 3, 2009/ US 7611966 B2	Intel Corporation	Eric J. Li, Sergei L. Voronov, Christopher L. Rumer	A method is described for laser scribing or dicing portions of a workpiece using multi-source laser systems. In one embodiment, a first laser melts portions of the workpiece prior to a second laser ablating the portions of the workpiece.

Exhibit 1 depicts patents related to laser micromachining process.

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