ABB's partnership with MIT and Leaders For Manufacturing program

ABB Corporate Research has a tradition of working with many leading universities around the world. Typically, these collaborations help keep the company up to date with emerging science and technology, which can then be adapted for the development or enhancement of ABB products, services and solutions.

Over the past few years, ABB has been benefiting from the knowledge and practices of manufacturing operations experts in academia. One such important collaboration is with the Massachusetts Institute of Technology (MIT). Through its manufacturing technology program, ABB is closely associated with MIT's Leaders For Manufacturing (LFM). This is a two-year graduate-level academic and research program in which students have the opportunity to become 'bi-lingual' in management and engineering sciences and leads to two master's degrees: one in engineering and one in management.

LFM in a nutshell

LFM was launched in 1988 in response to the needs of American companies to become more competitive. It is an active partnership comprising MIT's School of Engineering, Sloan School of Management, and industry. This partnership is dedicated to addressing the broad issues of manufacturing, such as product development, marketing and the supply chain. Together the partners develop, design, implement, and participate in a cutting-edge, integrative engineering and management program that gives them the knowledge, tools, and support they need to strengthen, lead and transform industry.

Through its academic structure, its research, and its outreach to other universities around the globe, LFM strives to integrate the total manufacturing enterprise with customers, suppliers, government and the community. The course tutors generally have connections to major companies, and can see first hand certain business practices and technology – both new and emerging – at work. LFM participants include a diverse mix of students and alumni, senior executives at companies such as Intel, ABB and Ford, and faculty from MIT's Sloan schools of management and engineering. Such a mix ensures that many of the students participating have solid credentials in engineering or science.

In addition to classes and lectures focused on improving manufacturing in the context of case studies and personal experience, students have an opportunity to apply these principles in real-world factory settings through several plant tours. They are offered a chance to comment on the running of the facility, often giving valuable input on how to improve certain processes within the plant. In 2003, a 16 day 'cross-country' plant tour included facilities at Kodak (Rochester, New York), Hamilton Sundstrand (Rockford, Illnois), Ford (Detroit), General Motors (Detroit), Agilent Technologies (San Francisco), Boeing (Los Angeles), Dell (Austin), and Honeywell (Baton Rouge).

ABB's commitment

The LFM program is dedicated to discovering the principles that produce world-class manufacturers and leaders, and translating those principles into teaching and practice. It ideally fits with ABB's Manufacturing Technologies program, which aims at introducing world-class manufacturing methods to ABB factories. This involves improving the speed, inventory levels and quality at ABB factories as well as supporting IT solutions and products for ABB manufacturing. To help it achieve these goals, ABB decided to join MIT's LFM program in spring 1999 as a managing partner, becoming one of the very few European companies to participate in the LFM.

As a managing partner, ABB plays a critical role in LFM program governance, overall program policy and operations, and internships. The most visible part of the partnership is perhaps that with internships. The LFM program includes a 26-week research internship at a partner company, during which students undertake a research project that exposes them to real manufacturing concerns. This takes place during the second year (usually between June and December).

Rafael O. de Jesús, leader of the University relations project within the manufacturing technologies program, (and a former LFM program student) coordinates activities with key universities. One of the tasks within this project is the coordination of LFM internships at ABB. Every year, between two and four LFM students complete their 26-week internship at various ABB sites. To date, 14 LFM students have completed internships within ABB business areas in Finland, Switzerland, Germany, USA and Ireland. Some of these students afterwards joined our company.

Being already very experienced, those attending the course tend to be given big projects, allowing ABB to benefit enormously from the results. Those on internship at ABB apply their know-how and experience to solving ABB problems. In addition, these people become aware of what ABB has to offer in terms of services and solutions, and this can be of benefit to the company they work for.

The research projects assigned to the students have varied. One student was given the task of investigating the application of Industrial IT technologies developed for process industries, such as pulp and paper, in a discrete manufacturing environment. The resultant feasibility study for a small instrument transformer plant in Finland led to a full pilot project in a much larger plant in Germany.

In 2002, following up on this work, another student was assigned to analyzing the findings of various Industrial IT project teams in the USA, Germany and Finland. These teams were working on the development of Industrial IT solutions for discrete manufacturing applications in ABB's Power Technologies division. Primarily, the student's task was to:

- Create a model for sharing acquired knowledge from pilot projects being developed within the company.
- Put together guidelines for rolling out future pilots.

In addition, the student had to come up with a business strategy for developing a marketable product from the results, and also for identifying areas of research needed to apply Industrial IT in shop floor and manufacturing execution control systems.

On a larger scale, faculty from MIT and students from the LFM program will work together on a recently commissioned ABB future factory project. Business areas within ABB are continuously

working to define a model of operational excellence. Within manufacturing, for example, certain activities are concerned with defining a manufacturing improvement methodology and IT integration standards for 34 factories. The future factory project will assist in these activities by producing a comprehensive research-based framework that will improve and accelerate the development and deployment of manufacturing operations excellence programs for all the business areas in ABB.

As well as offering internships to students, ABB is currently sponsoring one of its employees in the LFM program. The student in question is now completing her internship at Dell Incorporated in Austin, Texas. Her project is concerned with determining the optimal end-to-end order fulfillment process, from scheduling to shipping, which will result in maximum customer experience with minimum logistical cost.

Those who graduate from the program are very well qualified in both engineering and management. As one recent graduate said, “Because of the LFM course, I get the chance to wear many different hats. One day I am sitting with managers discussing business concerns, and the next day I am working with engineers on the shop floor solving technical problems.”

Give and take

As a large decentralized company with hundreds of companies in different stages of operational excellence, ABB has been able to provide the LFM program with many challenges – most concerned with finding ways to effectively improve a global corporation and its manufacturing operations. For students, internship experiences at ABB allow them to apply what they've learned at MIT to real-world problems. ABB employees have the opportunity to interact with LFM students, transferring knowledge to them, and vice versa.

As well as providing the challenges, ABB has benefited, as has MIT, enormously from the results of the various projects and research activities while contributing to a program that promotes the growth of future industry leaders.

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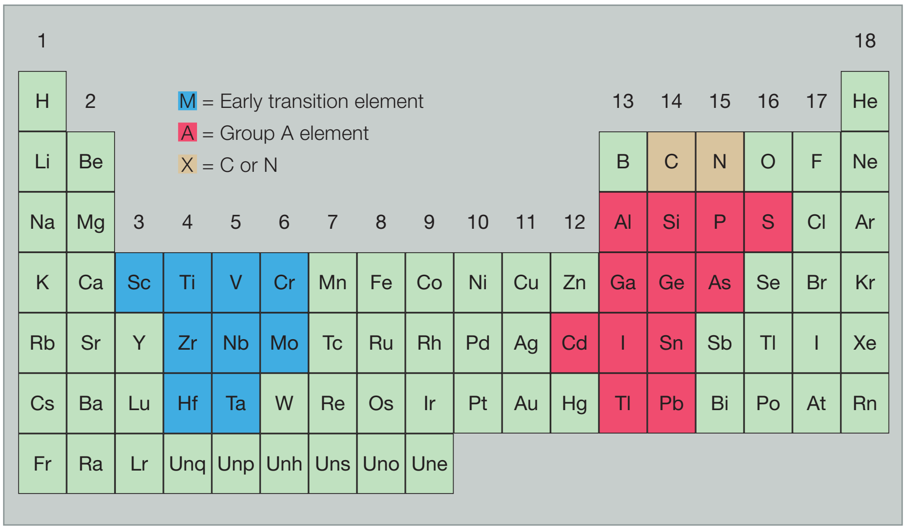
A new compound reduces contact wear

ABB is currently working on the development of a new contact film which possesses a unique set of properties well suited for contact and wear applications. The compound, Ti_3SiC_2, bridges the gap between ceramics and metals.

An article in *ABB Review 2/2003* called *Nanotechnology: from small dimensions to big business* [1] described ABB's activities in the area of nanotechnology and its growing importance to the company. It was explained that the strategy of ABB's nanotechnology program, in existence since 2000, is to focus on areas of nanotechnology and advanced materials – like electrotechnology, nanocoatings and nanosensors – which are less exploited and have direct relevance for ABB. The program secures technology transfer from the scientific community to ABB while helping ABB to find business opportunities. Biased towards applications rather than material development, the program aims to add new or improved functionality based on nanotechnology solutions to existing ABB products. The primarily short-term research activities target use in real products.

Within electrotechnology, the idea is to expand the electromagnetic property windows of essential materials and components in ABB products. This will lower the losses in electrical transmission and distribution network components, and reduce the weight and cost of systems. Important areas are thermal conduction, electrical insulation and contacts. It is the latter area – contacts – that is the focus of this article.

Periodic table of $M_{n+1}AX_n$ phases



M_2AX (211): Ti_2AlC, Ti_2SiC, Ti_2SnC… ~50 compounds
M_3AX_2 (312): Ti_3SiC_2, Ti_3AlC_2, Ti_3GeC_2
M_4AX_3 (413): Ti_4AlN_3, Ti_4SiC_3

Improving contacts

Electrical contacts and connectors are vital to the operation of many electrotechnical systems. In an ideal world, an electrical contact would exhibit low contact resistance, the right surface morphology (plasticity), good wear, good thermal conduction, oxidation resistance, arc resistance and non-welding properties. Unfortunately, in the real world, electrical contacts and connectors are often considered to be a system's weakest link.

To understand why this is so, consider that under any force mechanical contact surfaces only touch at a limited number of discrete points, called *a-spots*. Since most metallic surfaces (with the exception of gold) are covered with a native oxide, the true electrical contact is only a fraction of the mechanical one. Now consider that a contact should maintain low contact resistance over the lifetime of the product, with only limited degradation of the electrical contact properties. All this, despite the contacts being exposed to high temperatures due to current constriction, different chemical environments and wear due to thermal cycling and magnetostriction of the materials. Some contacts used in circuit-breakers must even withstand different sliding wear and current arcs that can cause local melting of the contact interfaces.

Soon, it may be possible to provide many of those ideal contact properties mentioned earlier. Through its nanotechnologies program, ABB is currently involved in the development of a new contact film which possesses a unique set of properties well suited for contact and wear applications. The material is a compound known as Ti_3SiC_2 – a member of a group of nanolaminar materials that bridge the gap between ceramics and metals. In other words, these materials exhibit metallic properties such as ductility, shock resistance, good thermal and electrical properties as well as ceramic properties like high temperature resistance, chemical inertness and wear resistance.

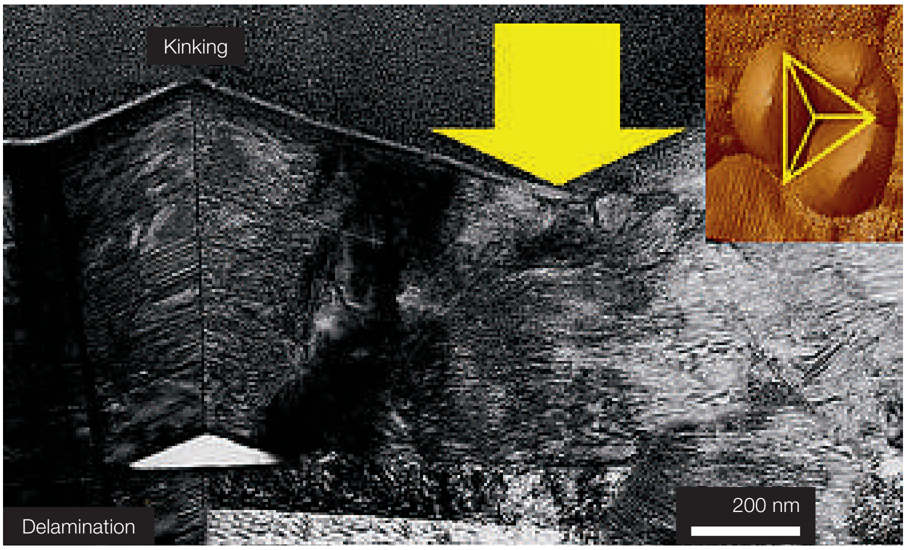


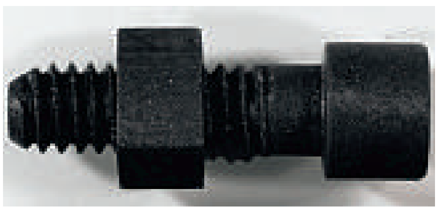
Image of an approx 1-µm-thick single-crystal MAX-phase layer after nano-indentation (arrow). The large pile-ups are characteristic of very ductile materials.
Source: J. Emmerlich and J. Molina-Aldareguia, Linköping University

MAX-phases

The nanolaminar materials are known as *MAX-phases*. These compounds have a layered crystal structure and can be described as ternary carbides (compounds made up of carbon and any other element other than hydrogen) or nitrides. The carbides and nitrides are present as nano-sized layers and are bonded to each other through considerably weaker Me-A bonds. The compounds have the general formula $M_{n+1}AX_n$, where M is an early transition metal, A is an element in group 13–15, X is carbon or nitrogen and n = 1, 2 or 3 (see periodic table). Currently, 60 different MAX-phases are known.

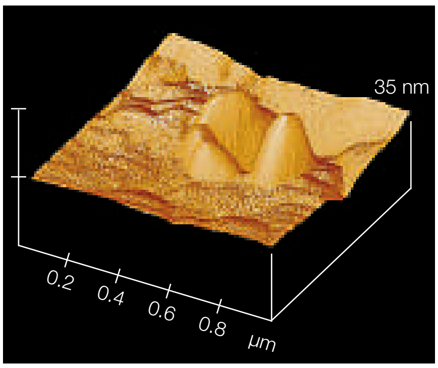
Even though the first MAX-phases were synthesized more than 30 years ago, their properties have hardly been investigated. The discovery that Ti_3SiC_2 displayed properties which are typically both metallic and ceramic is a recent one, and credit for this goes to a research group at Drexel University in the USA.

Under the leadership of Professor Michel W. Barsoum, the group found that Ti_3SiC_2 has high thermal and electrical conductivity (better than pure Ti) and exhibits one of the lowest friction coefficients of any solid measured to date. They also discovered that the compound has a high stiffness value combined with low density and a very high damage tolerance. Furthermore, it seems to maintain these properties at high temperatures and is also highly resistant to oxidation and thermal shock. A surprising property of Ti_3SiC_2 is that it is easy to machine, making it possible to produce different kinds of complex components.



Machined nut and bolt made from MAX ceramics
Source: M. W. Barsoum, Drexel University, and T. El-Raghy, 3ONE2, LLC

Ti_3SiC_2 is an unusually tough ceramic even at room temperature, because microcracking, delamination, crack deflection, grain motion and buckling of individual grains act as energy-absorbing mechanisms during deformation. This behavior has been attributed to the particular structure of the compound, enabling basal plane slip and giving it the ability to form kink bands under applied loads. Ti_3SiC_2 is stable up to 1800 °C in an inert atmosphere and decomposes at temperatures above 2300 °C. The resistivity of Ti_3SiC_2 at room temperature is 23 µΩcm, nearly half that of pure titanium, and the thermo-power (EMF) is zero over a wide temperature range, which means that equal quantities of electrons and holes contribute to conduction. Its thermal conductivity, at 37 W/mK, is good. In addition, oxidation properties are excellent and Ti_3SiC_2 is considered to be more oxidation resistant than



Nano-imprint in a MAX coating

University collaborations

ABB feels strongly that close contact between industry and academia is a vital factor in the product development process. The collaboration between ABB and Linköping and Uppsala universities in Sweden is largely responsible for the progress made in the development of the MAX-phase contacts. An important part of the work at these two institutions is synthesis and characterization of new MAX-phases which are of scientific and industrial interest. Kanthal AB participates in the collaboration as a developer and main supplier of bulk MAX ceramic material. As a result of the cooperation with Impact Coatings AB, Kanthal, ABB and the universities have established a new model where the parallel development of coating materials, and scaling and process design for industrial production is now the norm. Financing of the project for the development and commercialization of MAX phases is also provided by Vinnova, a Swedish agency for innovation.

Since 2001, The Thin Film Group at Linköping under Professor Lars Hultman and the Materials Chemistry Group at Uppsala with Professor Ulf Jansson have worked in close association with ABB's nanotechnology program. Based on this work, a growing number of publications are being prepared by the universities. The recognition the students earn through scholarships and prizes for their pioneering work has also led to job offers from industry.

chromium (Cr). Due to the limited mobility of silicon, a thick oxide layer is not formed at the top surface, allowing for a better electrical contact.

Due to the promising properties of Ti_3SiC_2, a project was initiated, within the nanotechnology program, at Linköping and Uppsala University in Sweden to investigate if Ti_3SiC_2 could be synthesized as a coating using a deposition process that could be adapted to industrial production. Using sputtering (ejection of material through energetic ion bombardment – a physical vapor deposition technique), initial attempts showed that a single crystal Ti_3SiC_2 could be synthesized above 700 °C, and a compound with good contact properties is formed at lower temperatures.

AFM (Atomic Force Microscope) picture showing terraces of material in steps of 1/2 and 1 unit cell

Applications

Applied to a vital part of a low-voltage product, Ti_3SiC_2 has shown excellent low friction and wear properties, and the next aim is to implement it in the product. A range of different ABB products is under investigation to see if the new contact layer contributes to new functions, prolonged lifetime and cost reduction.

Looking to the future

In the near future, Ti_3SiC_2 will undergo extensive tests to determine its long-term properties as a contact material in selected applications and/or products.

Also, in order to secure commercial usage of the material, a company called Impact Coatings AB is collaborating with the group. Its task is the commercial upscaling of the deposition process for the MAX ceramics. This partnership is of special interest as the process of converting the research into a product (normally started after the research has been completed) is now taking place in parallel, with the intent of saving substantial time to market.

In addition, new combinations of MAX ceramics will be tested in an attempt to lower the contact resistance and so enable them to be used in low force applications. Ti_3GeC_2 has already been synthesized and tested, with promising results, and the next step is to replace Ge with Sn, whose native oxides have semiconductor properties and are easily penetrable. The final aim is to be able to tune the properties of the MAX-phase to obtain the optimum coating.

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Reference

[1] **T. Liljenberg, O. Hjortstam, S. Volponi:** Nanotechnology: from small dimensions to big business. ABB Review 2/2003, 49–53.