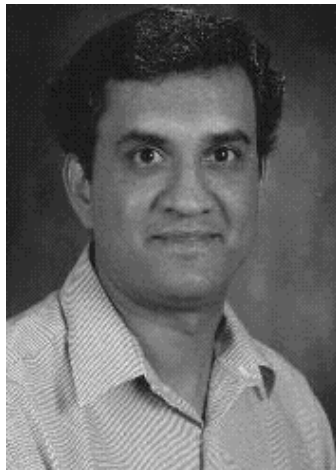


NSF Materials Research  
Science and Engineering Center

CENTER FOR THERMAL SPRAY RESEARCH

# Going Beyond The Surface

## Message from the Director: Dr. Sanjay Sampath



This second annual issue of the **CTSR** newsletter reflects important accomplishments and transitions. I took over the reigns of **CTSR** from Herb Herman in January 2002. Herb continues to be an active participant in the **Center** and is deeply immersed in understanding defect structures in thermal sprayed coatings: namely porosity. Herb, in his usual wit, calls it "the study of nothing". No doubt this integrated study of porosity has already shown its importance to the thermal spray community. We thank Herb for his exceptional leadership and contribution as the founding director of the NSF funded Materials Research Science and Engineering Center. We look forward to his continued contribution to the **Center** and the industry.

We are now in the third year of our second round of the NSF funded MRSEC program. I am pleased to report that our research is at an all time high and is

progressing exceedingly well on all fronts. Our fundamental research through our integrated interdisciplinary partnership has developed new insights into the thermal spray process and the characterization of the coatings. A few highlights of our important research results are included in this newsletter. Details of the work are available on our comprehensive web-site: <http://www.sunysb.edu/ctsr>. Be sure to explore the world of research nuggets where we highlight our important research results in the form of web-based posters. This work has not only been of great value to the scientific community but has yielded important benefits to industry. Our **Consortium for Thermal Spray Technology**, led by Lysa Russo is making great strides in establishing this science-technology relationship and bringing the benefit of fundamental science to thermal spray applications.

On the personnel front, the **Center** has grown substantially both in the number of people involved as well as in interdisciplinarity. Again, our enhanced and updated website provides a snap-shot of the various people and activities. Our collaboration with mechanical engineering faculty in the area of process and microstructure modeling has developed nicely, yielding remarkable results and interactions. We have also actively involved faculty with interests

in materials physics, thermal sciences, geo-sciences and chemistry into the thermal spray world. In the same vein, we have gone beyond the boundaries of Stony Brook and sought academic alliances with MIT (Prof. Suresh) and the University of California at Santa Barbara. These alliances have been insightful and productive and have brought new ideas to the **Center's** fundamental research efforts. Put simply, we have realized the vision of NSF to bring together interdisciplinary and multidisciplinary approach to thermal spray materials.

The **Center** has radically expanded the applicability of thermal spray processes to functional surfaces. Two important activities are starting to yield dividends. The first is the **Center's** seed program in the area of precursor derived synthesis of functional oxides. We have produced a variety of optical and magnetic oxide films using this approach, allowing novel material developments. The DARPA sponsored Mesoscopic Integrated Conformal Electronics program is enabling thermal spray to fabricate multi-layer electronics and sensor structures. These initiatives, although in their early stage of commercialization, offer a long-term strategy for expanded use of thermal spray technology.

I invite you to join the Stony Brook team to realize our common goal: **to make thermal spray a household word!**

### Inside this issue:

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### Special points of interest:

- ??*CTSR appoints new Director, Dr. Sanjay Sampath*
- ??*Dr. Anthony Tether, DARPA Director, visits CTSR*
- ??*New Coating Sensor Technology licensed to ICS*
- ??*Lighting the "Flame" - Educational Outreach Opportunities*
- ??*Alumni Highlights: Dr. Bob Gansert and Mr. Mitch Dorfman*

Applications of thermal spray coatings have grown steadily over the last 30 years. However, despite the advances in process and materials technology, coating reliability and repeatability has prevented widespread use of thermal spray coatings and, in particular, the use of thermal spray coatings in prime reliant functions. One obstacle to obtaining greater coating repeatability and reliability is the inability to measure coating properties in real-time. In addition, critical intrinsic mechanical properties of importance to prime reliant design are rarely measured outside the realm of academia and national labs.

Recent developments at CTSR have paved the way for the development and commercialization of a real-time, *in-situ* evaluation of coating properties for both process development and process control. Dr. Jiri Matejicek and Prof. Sanjay Sampath have developed an apparatus and method for *in-situ* measurement of thermal spray coating properties for process development and control. This concept *In-situ Coating Property Sensor* (ICP), based on a novel approach to thermo-elastic curvature meas-

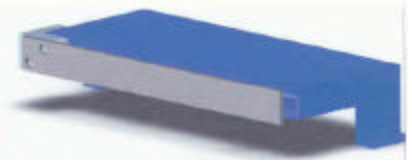
urement and analysis, allows for extraction of these properties *in-situ* and within minutes of the spray process completion. Elastic modulus and residual stress of the coatings have been measured which captures the essence of the coating (defects, interlamellar adhesion and microstructure). The method has been validated in the laboratory on a variety of materials systems (metals and ceramics) and processes (plasma and HVOF) yielding astounding results. A US patent was recently approved for this approach 6,478,875 and Integrated Coating Solutions, Inc (ICS) has obtained a license to develop and commercialize this technology.

Integrated Coating Solutions, in partnership with CTSR has completed a National Science Foundation (NSF) Phase I Small Business Technology Transfer program to assess the capability of this technology to not only monitor thermal spray coating properties but also to serve as an *in-situ* process control tool for thermal spray booth. The Phase I program enabled building of an alpha device based on the concept and was thoroughly tested for its capabili-

ties. A Phase II proposal has been submitted to NSF, which if funded will provide a two year technology development effort to translate the method into a product. Several engine manufacturers have expressed an interest to participate in this program.

By combining the industrial experience of ICS with the research resources of CTSR and with support from NSF, it is expected that this tool will soon become available to the thermal spray market place and will provide quantitative data on coating's microstructure and properties in an economical and timely manner.

ICP beta units are scheduled for release in late summer 2003. If interested in obtaining one, please contact Rob Greenlaw at ICS at [rgreenlaw@incoat.com](mailto:rgreenlaw@incoat.com).



**Model CB2—Next Generation ICP Property Measurement System**

## Consortium on Thermal Spray Technology

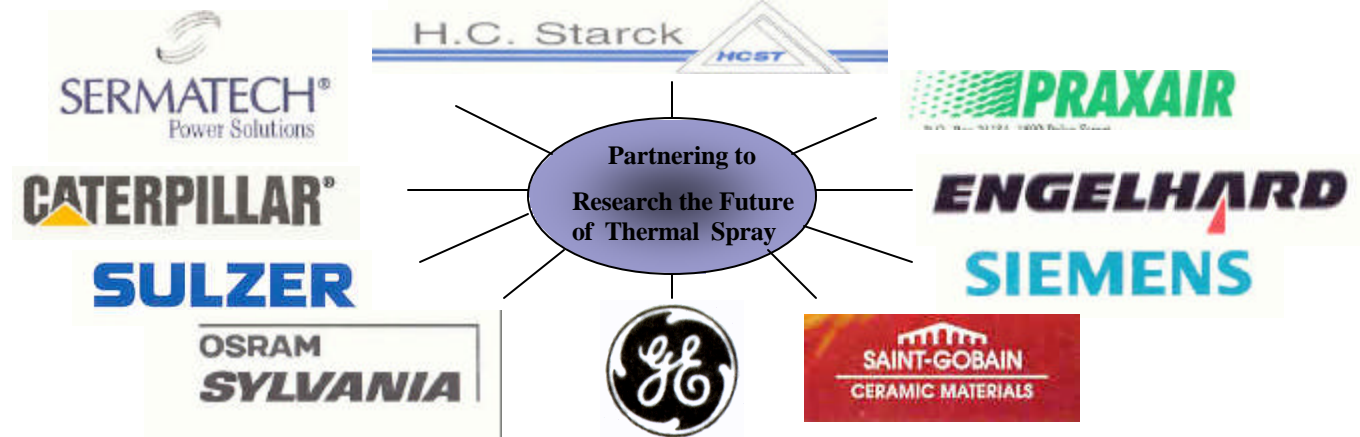
Through the *Center's* interdisciplinary research a deeper, more fundamental insight of thermal spray has been realized. This insight has revealed new paths to microstructural control allowing for the formation of functional surfaces for a host of novel and very exciting applications.

In May of 2002, the *Center* began to host a **Consortium on Thermal Spray Technology** that provides a forum for the

dissemination of these many advances to groups of companies that want to shape and revolutionize the direction of thermal spray processing. The benefits of membership are vast and include: shaping and participating industry related research programs, submission of coating samples, advanced access to Consortium generated research, use of the *Center's* state of the art lab and testing facilities and registration to the *Center's* annual workshop and Advanced Hands-on Training Class.

The Consortium is truly a collaborative forum where people from industry and members of the *Center* work as partners in exploring and pursuing novel properties of thermal spray coatings as well as innovative applications of thermal spray technology.

For more information or membership, please contact Ms. Lysa Russo at: [lysa.russo@stonybrook.edu](mailto:lysa.russo@stonybrook.edu)



# Research Experiences for Undergraduates goes International

Research Experiences for Undergraduates, or REU, is a National Science Foundation sponsored program where during the summer months undergraduate students are able to join in on research projects learning first hand how research is done. The International REU program incorporates an additional level of experience, that of another culture.

During the summer months a group of students from our Center, as well as other universities, travel to REU labs around the world and are assigned a specific research project. The students

work closely with faculty, post-doctorates and other graduate students not only learning the culture of the laboratory but that of the host country as well.

This past summer, two Stony Brook University students, Angela Yuan and Cassandra Holzgartner, had the opportunity to study abroad at the Czech Technical University in Prague.

“In addition to providing me with a rare research opportunity, the National Science Foundation also allowed me to travel abroad for the first time. As my

*“Not only did I receive the opportunity to study abroad but I also engaged with intelligent and gifted faculty and students. I gained a perspective that few other students can relate to but encourage them to pursue”, Cassandra “Casey” Holzgartner:*

first international travel experience, the Czech Republic was everything I expected and more. I was impressed by the beauty and history of the country as well as the kindness of its people”, Angela Yuan, Int’l REU student summer ‘02.

## Alliance for Defense Coating Technology

There are extensive and diverse coatings activities within the Department of Defense and in the industrial sector which have much in common. Widespread gains would be secured by DoD through assembling knowledge-based and coatings experience under one umbrella. An extensive range of industrial requirements and activities is reflected in the military, where costly and complex systems must function in the worst conceivable environments. For example, as a central goal of DoD’s “Affordability Program,” it is critical to judge the best and most cost-effective coatings solutions offered by applied research. However, coatings solutions are generally done on an application-to-application basis. It would be more appropriate to consider the introduction of novel materials and processes into both new and old problem areas.

The Navy, Army and Air Force all face persistent surface degradation problems, ranging from mundane to highly complex. There are means for solving these problems that are currently not specified in standards, but which offer substantial economical and operational awards. While numerous surface protection technologies are “off the shelf”, there are varied approaches which have yet to be recognized by government, and to a large extent, by industry.

The *Alliance for Defense Coatings Technology* offers a means through which military engineers and industrial surface protection specialists can combine forces to formulate the best coatings systems for high performance vehicles and machine elements. The *Alliance* will form a link between DoD and the *Center for Thermal Spray Research*, which has been established at the State University of New York at Stony Brook by the National Science Foundation to carry out research on the fundamentals of thermal spray science and engineering. As a further *Center*

*“An extensive range of industrial requirements and activities is reflected in the military, where costly and complex systems must function in the worst conceivable environments”*

activity, there is a program of Industrial Outreach, which has allowed major manufacturing and industrial organizations to participate in the work of the *Center*.

The *Alliance* has much to offer participants. Through the formation of such a confederation, a forum can address the problems facing today’s military, with full recognition of the evolving technologies that are currently emerging from the research laboratory.

The benefits of the *Alliance* include:

- ?? Exposure to state-of-the-art coatings and surfacing technologies
- ?? Interfacing with technologists from the military, industry and academia
- ?? Proposing research and development programs tied directly to DoD’s needs
- ?? Developing a link between research and practice in thermal spray and related fields
- ?? Participating in advisory and performance evaluation programs
- ?? Development of tomorrow’s military specifications

The *Alliance* welcomes your participation. For additional information please contact:

Professor Herbert Herman

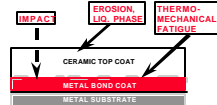
Phone: 631-632-8480

Herbert.Herman@stonybrook.edu



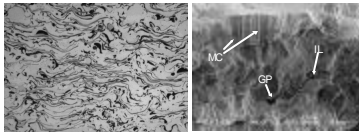
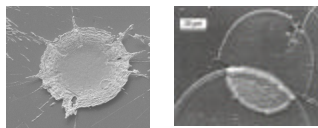
## INTRODUCTION

Thermal barrier coatings consist of a thermally insulating ceramic layer covering a metallic bond-coat layer. The bond coat provides oxidation protection of the substrate and reduces the difference in thermal expansion. The insulating ability is improved by its containing delaminations and pores. On the other hand, cracks could cause spalling and failure of the coating. Optimal microstructure of the top coating is not a homogenous one without defects, but is rather a structure containing pores and cracks of various types at particular locations in the coating.



## MICROSTRUCTURE OF PSZ COATINGS

- Deposit is built up by millions of "brick"-splats.
- Splat is formed by the interaction of droplet with substrate /or previously formed deposit.
- Droplet spreading and solidification behavior affects the splat dimensions, grain size and phase selection.
- Splat size, morphology and pile-up determines, to a large extent, the deposit microstructure, porosity and property.



IP – Interlamellar Pores GP – Globular Pores MC- Microcracks

### Particle/Flame

- Particle Velocity & Temp.**
  - powder morphology
  - partially or fully melting
  - evaporation/resolidification
- Particle Size Distribution**
  - trajectory
  - microscale heat transfer
- Turbulent Jet**
  - instability / random process
  - low stability / reproducibility
- Plasma flame**
  - electrode wear
  - fluctuation

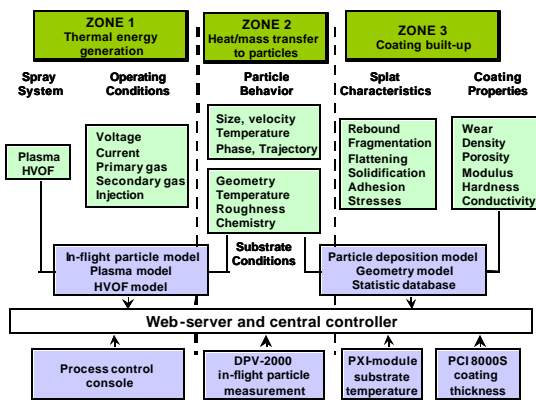
### Splat Formation

- Flattening / Adhesion**
  - substrate temperature
  - roughness
  - wetting / solidification
- Droplet Splashing**
  - velocity and size
  - solidification rate
- Splat Morphology**
  - flattening ratio
  - substrate melting
- Stress State**
  - residual stresses

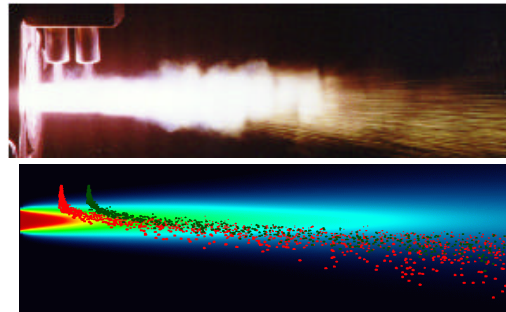
### Microstructures

- Interlamellar Pores**
  - enhances thermal barrier effect
  - Source of delamination
- Globular Pores**
  - introduces porosity/compliance
  - origin of failure
- Vertical Splat Microcracks**
  - relieve residual stresses
  - initiate during thermal cycling
- Vertical Macrocracks**
  - introduces in-plane compliance
  - entry of corrosion products

## INTERNET-BASED SIMULATION AND CONTROL THERMAL SPRAY SYSTEM



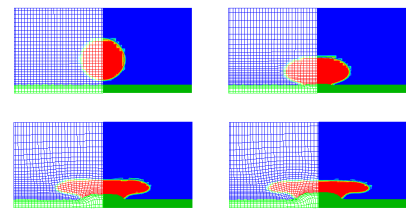
## 2D PLASMA JET FLOW AND FLAME/PARTICLE INTERACTION



Two injectors are used for two different powders. Injection velocity for PSZ is 14.5 m/s, much higher than that for NiCrAlY (9.8m/s).

## PHYSICAL MODEL

- Inertia force (impingement, shock wave)
- Surface tension (liquid/gas, triple point)
- Solidification (dynamics, kinetics, contact resistance)
- Moving free surface (shear stress)
- Instability and splash (Rayleigh, weber, capillary)
- Bond energy, adhesion, and trapping gas
- Microstructure

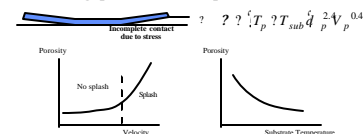


## PSZ COATING POROSITY

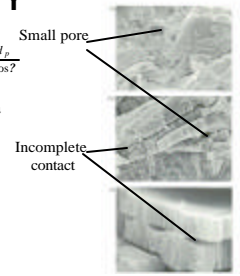
Pores are due to unmelted particles and splashing

$$\text{Melting Index } M.I. = \frac{V_p d_p}{T_p L} \quad \text{Splash Index } S.I. = \frac{T_p - T_{sub}}{T_p} \frac{V_p d_p}{1? \cos?}$$

Horizontal gap is due to incomplete contact



Difficulty: Particle size, velocity, and temperature are strongly inter-related.



## CONCLUSIONS

- Thermal Spray is a versatile deposit forming technology with increasing importance
- Fundamental understanding of splat formation is essential for optimization.
- The relation between the microstructure of the coating and the properties of the particles needs to be established, and the relation between the particle properties and the spray gun parameters needs to also be understood.
- Integrated model and quantitative characterization can help us to establish relationships between TBC microstructure and properties, and develop processing procedures to obtain desired microstructure.

# Thermal Spray MICE Sensors: A Clever Way to do an Age-Old Task—*Professor Jon Longtin*

Sensors abound in our world of modern engineering products and systems. The availability of inexpensive, powerful, and compact computing has resulted in a tremendous increase in the sophistication of devices and machines of all complexities, from airplanes to toasters. Sensors play an integral role in bridging the analog, real world with the digital domain.

Traditionally, sensors are integrated into engineering systems by mechanically attaching them to the structure to be sensed using glue, hardware, compression, etc. Such attachment schemes are prone to failure and represent a weak point in the system, and impose restrictions on the environment in which they can be placed. Also, traditional manufacturing technologies are limited in the materials they can use to fabricate sensors, with the consequence that many sensors have a limited range of applicability, particularly for extreme or harsh environments.

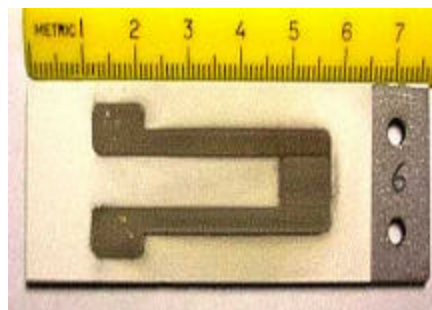
Enter thermal-spray technology. *MICE*, which stands for *Mesososcopic Integrated Conformal Electronics*, is an emerging technology in which traditional thermal spray is being utilized in innovative new ways to produce a host of new and, in some cases, unrivaled sensor systems. Sensors fabricated using thermal spray offer several unique advantages. They can be embedded directly onto a

component, and even placed underneath a traditional thermal spray coating. Since thermal spray has such enormous material versatility, materials for sensors can be chosen that are extremely robust, and, as such, can withstand the extremes of harsh environments, including very high temperatures, corrosion, vibration, and wear. The sensors, once deposited, are ready to work *immediately*; there is no post-firing or other high-temperature operations required for them to become functional—a significant advantage. Also, depending on the application, the substrate temperature increase can be very small. As a consequence, plastics and polymers, cloth, and other temperature-fragile materials can have sensors fabricated onto them.

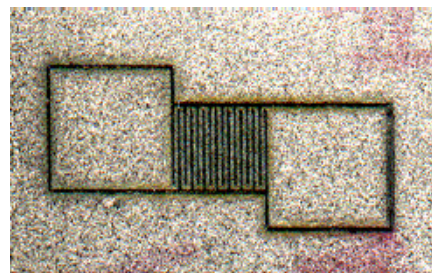
Thermal Spray MICE research at Stony Brook focuses on a variety of inter-related topical areas including fundamental materials research, sensor design and fabrication, testing and validation, and solution-oriented problem solving for specific applications. An example of a thermocouple and a micro-heater are shown in Figures 1 and 2, respectively, and have been produced by new, proprietary techniques.

The original MICE effort was funded by a generous grant from DARPA. As the DARPA program comes to an end in the coming months, efforts are being made to

continue the MICE work by interacting with industry and other government branches. In fact a variety of diverse companies have expressed interest in our MICE technology, and the MICE team continues to work with students, industry, and other academic institutions to further this exciting new technology.



**Figure 1: Thermal Sprayed Thermocouple**



**Figure 2: Patterned Micro-heater (approximate size 1cm)**

## DARPA Director, Dr. Anthony Tether, visits CTSR

March was a very auspicious month for many reasons. Not only did winter's freeze begin to thaw, the *Center* was proud to welcome a very distinguished guest visitor, Dr. Anthony "Tony" Tether.

As the Director of the Defense Advanced Research Projects Agency (DARPA) within the Department of Defense, Dr. Tether is responsible for the management of the Agency's vast array of projects for the research, development, and demonstration of concepts, devices and systems that provide highly advanced military capabilities.

Dr. Tether came to the laboratory to get a first-hand look at the progress



**Dr. Tether (6th from right, back-row) and MICE Team.**

being made on the fabrication of meso-scopically integrated conformal electronics through adapted thermal spray processing. This project, which has been funded by DARPA for the past two years, has received much attention over the past several months.

Dr. Tether was quite impressed, not only by the technology adaptation and implementation, but by the impressive pool of hard-working, multi-talented engineers that have joined forces to work together on this highly visible project. Their enthusiasm and determination is clearly evident to all who visit the lab.

# Lighting A “Flame” For Science: Educating the Next Generation of Engineers and Scientists

One of the most memorable comments made by a young student who came to the *Center* was that thermal spray is “so hot that it is cool”! This saying has become the motto of our lab’s educational outreach activities. Lighting the “flame” for a young person’s desire to pursue a career in engineering or the sciences is one of the most rewarding things that we accomplish here.

We offer middle and high school students a host of opportunities to interact with our lab, ranging from one-day field trips to summer internships, where students are able to work side-by-side with graduate students, faculty and post-doctorate staff members in conducting state-of-the-art research on a wide variety

of topics. A young high school student who recently visited the lab wrote, “The field of Material Science and Engineering was not one that I had heard of prior to my field trip to the *Center for Thermal Spray Research*, but after learning about it, I thought that this is the field of sci-



ence that I had been seeking for my summer research!”

The *Center* is also very involved with a variety of educational opportunities for undergraduate students. REU, Research Experiences for Undergraduates and International REU, are student exchange programs designed to expose students to other laboratory environments and cultures. Participating Universities include: UCLA Santa Barbara, Massachusetts Institute of Technology, Institute of Plasma Physics, Academy of Sciences in the Czech Republic and the University of Auckland, in New Zealand and the University of Limoges, University of Sherbrooke, Quebec.

## “Life Cycle Assessments of Thermal Spray Coatings” Workshop hosted by CTSR

On October 2002, the *Center* hosted a two day workshop focusing on Life Cycle Assessments (LCA) of thermal spray coatings. Life cycle assessments are a relatively new concept in which a detailed examination of the “cradle to grave” life of a product is thoroughly investigated. LCA’s are a potentially powerful tool that can help manufacturers analyze their processes and ultimately improve their products.

The workshop was attended by close to a hundred participants from around the globe, representing key coating suppliers, specifiers, researchers and end-users.

The session was kicked-off with plenary discussion on the overall state of the economy since 9-11 and an industry-specific discussion on the role of coatings for life cycles assessments for power generation systems. A round table discussion was convened on ways in which thermal spray can broaden its commercial market base.

Topics included Process-Performance-Economics for High Temperature Coatings and Feed-stocks along with Industrial Considerations for Thermal Spray Coatings.

Session speakers included:

?? John Stringer / Electric Power Research Institute

*“The workshop is my best way of learning more about new efforts with respect to conventional applications and for keeping up with the advances in new technologies”*

?? David Wortman / GE/University of Virginia

?? Matthias Oechsner / Siemens

?? Herbert Herman / SUNY Stony Brook

?? John Helm / Sermatech Power Solutions

?? Jeff Brogan / Poly-Therm Corp

?? Bruce Sartwell / Naval Research Lab

?? Christian Moreau / NRC

?? Sanjay Sampath / SUNY Stony Brook

?? David Hawley / Sulzer Metco

?? Larry Pollard / Progressive Technologies



## Alumni Focus: Dr. Robert Gansert—Hardface Alloys, Inc.

Bob Gansert's thermal spray career began upon entering graduate school at SUNY Stony Brook after working in a Department of Defense R&D Laboratory for 9 years. His interest in thermal spray was sparked by his brother, Daren's great enthusiasm for the field. Daren too is a Stony Brook graduate. At SUNY, Robert conducted his doctorate work in thermal spraying of free-standing ceramic forms using high-power plasma.

Upon graduation from Stony Brook, he began his career in thermal spray at Hardface Alloys, Inc. a manufacturer of equipment and materials for the Thermal Spray Industry. He is the Director of Engineering and is responsible for engineering, systems and specialty R&D projects (e.g., coatings for semiconductor applications).

While working for the Department of Defense, Bob conducted engineering and systems integration in advanced submarine systems programs. One of the highlights of his DoD career was a two-year special assignment to the Pentagon in Washington,

DC, in a \$6 Billion technical program office. This DoD engineering background combined with his thermal spray education has provided a synergy that Bob successfully applies and enjoys in HAI's automated



thermal spray systems.

Bob is a member of ASM, American Ceramic Society, published various papers, has several patents, and received numerous achievement awards from the DoD.

And now a word about Bob from Profes-

sor Herbert Herman, " Bob came to see me following his brother Daren's departure from Stony Brook. Bob was (still is) a serious fellow, but he had a glint in his eye. He wanted to return to school for his advanced degree. We talked a lot about his background and goals, his family (who I came to know well) and what kind of research might interest him. Happily, he was game to jump into an NSF—Industrial program carried out with the Czech Water-Stabilized Plasma torch. Bob's research was exemplary. He carried out a program which resulted in accolades from our industrial partners and resulted in a renewal of the contract. Aside from a Ph.D degree, the other thing that Bob took away from Stony Brook was a wonderful wife, Jenny, who received her M.D. degree about when Bob received his graduate degree. And the glint? - he became the practical joker of the lab. I should also note (with due respect to my other students) that Bob was a super dog sitter! We all miss Bob. He has made us and our *Center* proud."

## Distinguished Alumni Award Presented to Mr. Mitchell Dorfman, Sulzer Metco



Mr. Mitchell Dorfman

research institutions.

Mitch has spent most of his career at Sulzer Metco, developing new methodologies and chemistries for thermal spray materials, resulting in close to a dozen patents for novel technology and material developments.

All throughout his career Mitch has worked closely with all levels of industry personnel, helping to increase their understanding and awareness of the various as-

For over twenty years Mitchell R. Dorfman has been without doubt one of the most valuable contributors to the thermal spray industry, working closely with vendors, OEMS, universities, job shops and



pects of thermal spray technology.

Mitch has shown himself to be a proven mentor, working closely with many junior

colleagues in helping to develop both their professional and technical skills.

In addition to being the Director of Coatings and Materials Development at Sulzer Metco (US) Inc., Mitch is a Board member of ASM's Thermal Spray Society and Chairman of the ASM TSS Information and Development Committee.

The *Center for Thermal Spray Research* is proud to recognize Mitch as one of its own and on October 30, 2002 was pleased to present Mitch with this year's Distinguished Alumni Award during an evening banquet ceremony.

Alumni are selected based upon their contributions to the thermal spray industry, both academically and commercially, and must demonstrate a passion for making thermal spray a thriving and successful selection for surface modification and enhancement.

**CENTER FOR THERMAL SPRAY  
RESEARCH**

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[www.stonybrook.edu/ctsr](http://www.stonybrook.edu/ctsr)

## The CTSR Family: Hard at Work, and at Play!

