WESTINGHOUSE AND SGS TOOL

Plasma Technology for Production of Low-cost Diamond Film

Diamonds not only are beautiful and valuable as jewelry, they also have a number of unique characteristics that make them valuable in a range of commercial applications, including optics, acoustics, medicine, electronics, tooling and hard coatings, abrasives, and ceramics. Economic and technical constraints, however, limit their use. A low-cost method of depositing diamond film would open the way to the cost-effective use of diamond coatings for a wide range of industrial applications.[1]

COMPOSITE PERFORMANCE SCORE
(Based on a four star rating.)
★ ★

Diamond Coated Tools Offer More Than Sparkle

High-performance industrial cutting tools, such as drills, are used for machining demanding materials in the automobile, aerospace, and other industries. For example, in the aerospace industry, Boeing alone currently uses on the order of 11 million drill bits per year. There is opportunity for substantial productivity gains by extending the useful life of industrial cutting tools. Not only could the replacement costs of tools be reduced, but so too could the accompanying production downtime that results when tool replacement is required.

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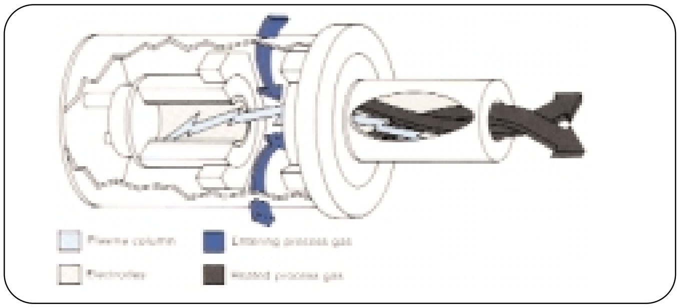
Diamond coatings would harden the tools and extend their lives. The feasibility of utilizing diamond-coated tools, however, depends on the ability to apply diamond coatings at a lower cost. And, key to making diamond films cost effective for application to a broad range of industrial cutting tools is the ability to coat larger areas more quickly at a lower cost per carat than is currently feasible. Current limitations on the size of the area of deposition mean that costly process repetition is required to coat large cutting surfaces.



As shown in the above figure, the plasma torch consists of a closely spaced pair of tubular water-cooled electrodes within which an electric arc discharge is magnetically rotated at extremely high speeds. During operation, a process gas is injected into the heater through a space (approximately 1 mm) between the electrodes.

Westinghouse Electric and SGS Tool Company Propose to Solve the Problem

In 1992, Westinghouse Electric Corporation and SGS Tool Company teamed up to propose to the ATP a joint-venture project to develop a low-cost diamond film deposition process. The Westinghouse/SGS team proposed an approach for diamond film deposition based on arc plasma chemical vapor deposition (CVD) technology. The team's specific focus was diamond film coatings for high-performance rotary tools.

[1] Status and Applications of Diamond and Diamond-Like Materials: An Emerging Technology, National Material Advisory Board, NMAD-445, 1990.

At the time of the project, several competing technologies were used to apply diamond coatings, including the basic CVD approach proposed for research by the Westinghouse/SGS team, but only in small areas and at high cost.[2] Westinghouse researchers proposed to concentrate on the arc plasma chemical vapor deposition (arc plasma CVD) process because they judged it to offer the best potential for achieving the desired complex of features: high deposition rate, high quality, and acceptable (per carat) cost.

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In 1992, ATP awarded the Westinghouse/SGS team $2.473 million for a three-year project. Westinghouse and SGS together contributed $3.275 million, for a total project budget of $5.748 million.

Westinghouse aimed to increase the power of existing hot cathode plasma torch technology from 15 kilowatts (kW) to a power level of 1,000 kW, or 1 megawatt (MW). Westinghouse/SGS hoped thereby to increase the maximum coating area from roughly 80 to roughly 6,500 square centimeters, and the production rate from about 1 carat per hour to at least 100 carats per hour. By using this approach, they saw the potential of reducing the cost of diamond coating from over $30 per carat to less than $5 per carat. The team also aimed further to cut production costs and increase production rates through an integrated gas recycling process, which would reduce the need for expensive, time-consuming gas replacement.

The team sought to overcome an additional problem: the targeted high-performance rotary tools are made from a tungsten-carbide alloy. The material contains traces of cobalt, and diamonds do not adhere well to cobalt.

The Arc Plasma Chemical Vapor Deposition Process

In arc plasma CVD, gas that contains carbon passes through an arc chamber. This electrically charged chamber superheats and ionizes the gas, creating plasma. The plasma, rich in carbon ions, is projected through a plasma jet onto the substrate (or surface) to be coated. As the plasma cools, the carbon atoms deposit on the substrate as tiny diamond crystals (a particular type of carbon structure), which form a diamond film. This technology is also referred to as the hot cathode plasma torch process.

Increasing torch power was considered critical to success. It would allow for diamond coating to be deposited over a larger area with each run of the plasma torch, thereby increasing the production rate. Because the process would need to be repeated fewer times to coat the same amount of surface area with diamond film, the cost per carat of diamond film would be reduced.

Complementary Know-how of Team Members

Westinghouse Electric had experience in the development and production of high-power, commercial plasma torch systems. These units are based on cold cathode, nontransferred arc technology. The company had also developed a 15 kW hot cathode plasma torch that was capable of extremely low electrode contamination in the plasma plume. Furthermore, it also enjoyed a leading position in the development of diamond coatings for optics, as well as R&D capabilities in the use of CVD for diamond coating.

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SGS Tool, a leading supplier of precision cutting tools, had product research capabilities in materials testing, product geometry, and coatings. In addition to experience in developing and producing these tools, SGS brought an understanding of customer needs. SGS Tool was to provide an automated platform that would manipulate the tool surfaces to be coated as required by the CVD process. SGS also would test and evaluate tools featuring the diamond film coating.

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[2] These include arc plasma chemical vapor deposition (CVD); high-temperature, high-pressure; oxy-acetylene flame; microwave plasma CVD; hot filament-assisted CVD; and radio frequency (RF) plasma CVD.

PROJECT HIGHLIGHTS

PROJECT:
To promote the development of an arc plasma CVD process as a low-cost method of depositing diamond film coatings on high-performance rotary cutting tools, by increasing the power of hot cathode plasma torch technology from 15 to 1000 kilowatts, and developing an integrated gas recycling process to decrease production costs.

Duration: 1/15/1992 – 11/14/1995

ATP Number: 91-01-0261

FUNDING (in thousands):

ATP	$2,473	43%
Company	3,275	57%
Total	$5,748	

ACCOMPLISHMENTS:
Although the Westinghouse/SGA team failed to achieve its overall goal of developing a cost-effective process for coating high-performance rotary tools with diamond film, it achieved noteworthy technical advances. Specifically, the team:

- increased the power of the hot cathode plasma torch from 15 kW to 100 kW;
- developed an integrated gas recycling process that eliminated the need for gas replacement, thus avoiding the need to interrupt the operation of the plasma torch;
- disseminated technical accomplishments in a 1999 technical publication, as well as through the mobility of researchers who served on the team; and
- set the stage for continued development of the technology by others.

COMMERCIALIZATION STATUS:
Westinghouse discontinued work on arc plasma CVD for diamond film deposition following the completion of the ATP project, mainly because it was unable to overcome the problem of adherence of diamond film to the tool surfaces being studied. Work on the development and application of the shot cathode plasma torch has continued elsewhere: Westinghouse Plasma Corporation was formed to acquire the plasma torch technology group from Westinghouse Electric Corporation. The new company is exploiting the commercial potential of the hot cathode plasma torch technology in testing thermal coatings for gas turbines.

OUTLOOK:
The outlook is brighter than might be expected, given the failure of the initial effort to achieve the overall project goal. The significant increase in torch power that was achieved in the project has enabled the newly formed Westinghouse Plasma Corporation to pursue applications of the hot cathode plasma torch technology to test the performance of alternative thermal coatings in the U.S. Department of Energy's Advanced Turbine Systems (ATS) program. The plasma torch achievements of the ATP project have greatly accelerated this effort and reduced its cost. In addition, the integrated gas recycling process that was developed in the project may prove useful in other applications.

Composite Performance Score: ★ ★

COMPANY:
Westinghouse Plasma Corporation
Waltz Mill Site, Plasma Center
P.O. Box 410 Madison , PA 15663-410

Contact: Dr. S.V. Dighe
Phone: (724) 722-7050
E-mail: dighesv@westinghouse-plasma.com

Subcontractor: University of Minnesota

Researchers from the University of Minnesota Department of Mechanical Engineering were brought into the project on a subcontract basis by the Westinghouse/ SGS Tool joint venture for their expertise in plasma torch modeling and plasma chemistry experimentation. These researchers were to evaluate alternative carbon gas feedstocks to be used to create the plasma. The researchers also were to undertake plasma flow modeling to inform the design of the plasma torch for application to the CVD process.

The team failed, however, in its overall goal to develop a cost-effective process for coating rotary tools with diamond film.

Some Success, Some Failure

The project succeeded in substantially increasing the power of the hot-cathode plasma torch from 15kW to 100 kW, and this increase in torch power is proving useful. The project team also successfully developed an integrated gas recycling process that eliminated the need for gas replacement, one of the problems that drove up deposition costs by interrupting the operation of the plasma torch. Information on this process was disseminated by the researchers in a recent publication, and may prove useful in other applications.[3]

The team failed, however, in its overall goal to develop a cost-effective process for coating rotary tools with dia-

[3] Martorell, et al., "Gas recycling and flow control for cost reduction of diamond films deposited by DC arc-jet," Diamond and Related Material, 8 (1999), pp. 29–36.

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mond film. The team was unable to develop a means of getting diamond coating to adhere to the surface of tungsten-carbide tools. It also failed to increase torch power to the target of 1,000 kW, achieving 100 kW instead. With these technical failures, the team could not proceed to scale up the arc plasma CVD process. As a result, Westinghouse discontinued its work on arc plasma CVD for diamond film deposition following completion of the ATP project, and subsequently sold off the divisions in which the work was carried out.

Technological Advances Carried Forward by Others

But the story does not end there. A management group, including former employees of the Westinghouse Science and Technology Center, bought the plasma torch technology and formed the Westinghouse Plasma Corporation (www.westinghouse-plasma.com) to exploit the commercial potential of the technology developed in the project. It has continued work on the development and application of the improved hot cathode plasma torch. The newly formed company is now applying this hot cathode plasma torch technology in a U. S. Department of Energy (DOE) Advanced Turbine Systems (ATS) program to develop thermal coatings for gas turbines. Hot cathode plasma torch technology is being used to test the performance of alternative thermal coatings, which would allow gas turbines to operate at higher temperatures and higher efficiencies.

According to a company member who was involved in the ATP project and the current DOE work, the accomplishments of the ATP project have accelerated the current ATS effort on the order of five years and have resulted in millions of dollars of savings by eliminating the need for a conventional high pressure test facility.[4] Hence, the technology developed in the ATP project is having important consequences for electric power generation—an unplanned, but noteworthy, benefit.

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These developments—the original innovating firms ending their involvement with the technology and other organizations picking it up and carrying it forward—demonstrate how the ATP's perspective of success can differ from a company's. The ATP views a proposing company as the mechanism by which accelerated application of the newly developed technology by one or more U.S. companies can be fostered. But that is not the only route to achieve benefits, as is demonstrated in this case. Project benefits that accrue to other U.S. organizations and individuals—spillover benefits—together with benefits that accrue directly to the innovating organizations, comprise the national benefits that the ATP was established to deliver. This case also demonstrates that technology development and implementation seldom proceed along a smooth path exactly according to preconceived plans. Rather, there are often twists and turns, and partial successes and failures, along the way.

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[4] Telephone interview with Dr. S.V. Dighe, Nov. 21, 2000.