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# SiC line deposition using laser CVD

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ABSTRACT

This study demonstrates the deposition of silicon carbide (SiC) lines by Laser Chemical Vapor Deposition (LCVD). SiC lines were deposited on a graphite substrate using the precursors methyltrichlorosilane (MTS) and $H_2$ and were characterized using Scanning Electron Microscopy. To fabricate neat shaped SiC lines, response surface experiments were employed to correlate the volcano effect with laser power, laser scan speed, and MTS concentration. The processing conditions for generating volcano-free SiC lines were determined to be an average temperature of 1020–1100 °C over a circle region of 350 μm in diameter, ratios of $H_2$/MTS from 13.2 to 30, and laser scan speed from 0.04 to 0.08 in./min.



## 1. Introduction

SiC (silicon carbide) is extremely hard, and has high thermal conductivity and good resistance to corrosion and thermal shock. It is a great material for high-temperature structural and wear-resistant applications, especially in harsh environments, such as heavy compressive loads and/or high corrosion. SiC is currently used for critical parts of uncooled gas turbine, uncooled adiabatic diesel engines, and high temperature bearings. It is also a good wide band gap semiconductor material, which is suitable for high temperature, high frequency, and high power electronic applications.

Conventionally, SiC is processed by various sintering techniques, such as pressure-less sintering, reaction sintering, etc., or by hot pressing. Because of the strong covalency of SiC, it is difficult to fabricate high density SiC materials unless sintering aids are added. CVD (Chemical Vapor Deposition) is another technique that is used to fabricate SiC. CVD-SiC is typically very dense and has much better properties than material fabricated by sintering or hot-pressing.

Laser Chemical Vapor Deposition (LCVD) is a process of utilizing a laser to heat up either the substrate or the precursors to initialize chemical reactions that deposit solid materials onto selected regions of a substrate. It is a useful technique for fabricating high precision, complex, micro sized ceramic and metal parts. Since the first structure was produced using LCVD in 1972, various shaped structures with various materials had been synthesized, i.e., fibers, lines, micro-springs, scaffolds, micro-solenoids, and antennae (Jean et al., 2002a,b; Mi et al., 2003; Pegna et al., 1997; Lehmann and Stuke, 1991; Maxwell et al., 1998; Boman et al., 1992; Dean et al., 1999). LCVD has been used as a ceramic welding process for joining ceramic tubes. With large laser spots, LCVD is used to coat a thin uniform layer onto thermally conductive materials.

Noda et al. (1992, 1993) deposited SiC films from $SiH_6/C_2H_2/H_2$ using photolytic-LCVD with an ArF excimer laser on a carbon substrate at 518 K. They found that the deposition rate was determined by the photolysis of $SiH_6$ alone. The crystal structure of the deposited SiC films was changed from amorphous to crystalline β-SiC when the amount of $SiH_6$

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was increased. Suzuki et al. (1994) synthesized SiC films by applying the laser beam either perpendicular or parallel to a graphite substrate using photolytic-LCVD technique. The major constituent of the deposits was microcrystalline β-SiC when the laser was perpendicular to the substrate. On the contrary, when the laser was parallel to the substrate, the deposits were amorphous SiC with some carbon. Crocker et al. (2001) used SALDVI (Selective Area Laser Deposition Vapor Infiltration) to consolidate various material powders by depositing SiC materials into the pores. Ghayad et al. (2001) used the SALD (Selective Area Laser Deposition) to join ceramic parts with SiC materials, so as to manufacture complex components.

Limited literatures exists concerning the fabrication of SiC parts directly using the LCVD technique. In order to fabricate 3-D complex SiC parts, it is first necessary to learn how to fabricate good quality lines and fibers. These basic shapes are the building blocks for manufacture of complex shaped parts. This research here demonstrates how to deposit SiC lines without the volcano effect using LCVD technique. The volcano effect refers to the depression at the top of the deposit, which makes the morphology of deposits similar to a volcano. Because of the Gaussian energy distribution of the laser beam and heat conduction within the substrate, there is a large temperature gradient across the reaction zone on the substrate during LCVD deposition (Duty et al., 2003). This high temperature gradient was reported as the major cause of the volcano effect for LCVD SiC fibers (Mi et al., 2006).

## 2. Experimental procedure

A detailed description of the Georgia Tech LCVD system can be found elsewhere (Duty et al., 2001, 2003). The novelty of this system is the addition of an angled gas jet, which is used to deliver reagents directly to the reaction zone to enhance the deposition rate. The system consists of two chambers, an upper chamber and a lower chamber. The lower chamber houses the stage system that is used to move the substrate and the upper chamber is where the actual chemical reactions occur. The system is equipped with an infrared $CO_2$ laser having a Gaussian energy profile with a maximum power output of 100 W. The laser beam is delivered to the substrate through a series of mirrors, a beam collimator, and a focusing lens. The distance between the focusing lens and the substrate is about 45 cm. The laser is controlled by applying 0–10 V to the laser controller, which converts the voltage to a pulse signal driving the laser. The experimental relationship between the laser power and applied voltage is shown in Eq. (1), where $P$ is the laser power in W and $x$ represents the input laser voltage in V. In this study, applied voltages of 3 and 6 V were frequently used. The corresponding laser powers are 44.6 and 76.3 W. The diameter of the focused laser spot is 200 μm. The laser beam is fixed and the substrate is moved during the deposition process to generate various structures. In this study, the laser scan speed refers to the speed of the laser beam relative to the substrate, which is actually the speed of substrate. To deposit multilayered SiC lines, the substrate is repeatedly moved forward and backward horizontally.

$$P = 0.0067x^3 - 0.8261x^2 + 17.575x - 0.8496 \quad (1)$$

MTS (methyltrichlorosilane) was selected as the precursor for depositing SiC because it is inexpensive and less toxic compared to other types of precursors. Importantly, considerable prior CVD experience exists for the deposition of SiC from MTS. During the CVD-SiC deposition process, $H_2$ is typically added to assist the decomposition of MTS. MTS is a liquid under room temperature and one atmosphere. In order to transfer gaseous MTS into the upper chamber of the LCVD system, a vaporizer was used as shown in Fig. 1. First, a measured $H_2$ flow was introduced into a vaporizer through MFC1 (Mass Flow Controller); then the vapor mixture of MTS and $H_2$ flows out of the vaporizer through the outlet pipe. As

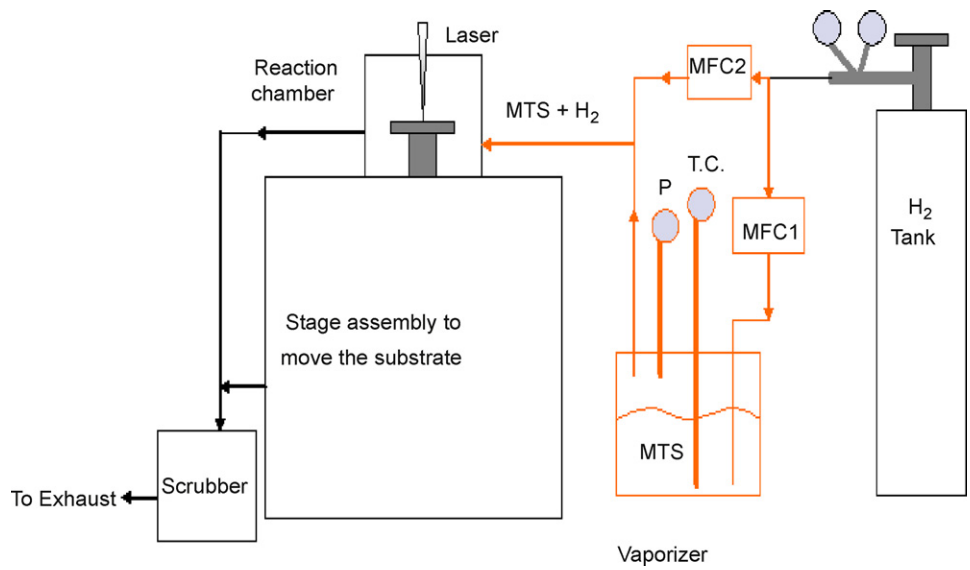


**Fig. 1 – Reagent supply system for LCVD of SiC.**