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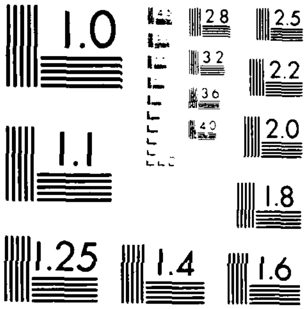

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The Quartz Envelope Heater: A New Heating Technique for MOCVD Systems

S. I. BOLDISH, J. S. CIOFALO,
and D. H. BARKER
Electronics Research Laboratory
Laboratory Operations
The Aerospace Corporation
El Segundo, Calif. 90245

16 May 1983

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Los Angeles, Calif. 90009

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This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Gregory A. Welz	Norman W. Lee
Gregory A. Welz, 2nd Lt, USAF	Norman W. Lee, Jr., Colonel, USAF
Project Officer	Commander, Det 1, AFSTC

REPORT DOCUMENTATION PAGE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The quartz envelope heater, a new heating apparatus designed specifically for metal organic chemical vapor deposition, is described. Discussed as well are its advantages over traditional heating techniques, such as RF induction heating and quartz lamp heating. The apparatus also has more general application to any chemical vapor deposition system which requires a single temperature zone to a maximum of 800°C and which does not contain reactants that chemically attack quartz glass.

CONTENTS

FIGURES

I. INTRODUCTION

The heater is an important part of a metal organic chemical vapor deposition (MOCVD) system, because it must heat the substrate to approximately 700°C, causing gaseous constituents to decompose or react to form the epitaxial layer. The heating apparatus must meet the following criteria: (1) be able to heat the substrate uniformly; (2) maintain a constant temperature for up to 30 min; and (3) not contaminate the substrate or epitaxial growth. RF heating and high-intensity quartz lamp heaters, commonly used to heat substrates during the growth of GaAs and GaAlAs by MOCVD, meet the above criteria. Both, however, have weaknesses, discussed in Section IV, that are avoided by the heater described in this report. The new technique, developed at The Aerospace Corporation, uses a quartz envelope heater that employs resistance heating.

Sections II and III describe, respectively, the design and testing of the apparatus, and Section IV compares the quartz envelope heater with the other two heating methods. Conclusions are presented in Section V.

II. EXPERIMENTAL

Several quartz envelope heater designs were constructed and evaluated before achieving the one described here. This section details the construction of the heater, its thermal profile, and the factors that determine the successful heater design.

The inside of the quartz envelope heater, depicted in Figure 1, consists of a boron nitride (BN) core heater, a BN core heater top, a zirconia ceramic insulator, a platinum foil heat reflector, and a platinum/platinum-13% rhodium (Pt/Pt-13% Rh) thermocouple. The core heater has been threaded from top to bottom to hold a 20 mil Pt-20% Rh winding. The heater, insulator, and reflector are mounted on a quartz support contained in a quartz envelope (Figure 2).

In order to have a thermally efficient structure which enables the quartz envelope heater to reach a surface temperature of 700°C without overheating the Pt-20% Rh heater windings, BN was used to hold the windings. Boron nitride was selected because it has high thermal conductivity, good thermal stability, good electrical insulation, and good machinability; Pt-20% Rh heater wire was selected for resistance heating because it withstands high temperatures. The BN was grooved and threaded with a lathe to make it easier to wind the heater wire uniformly and snugly. That construction permits a predictable temperature profile on the top surface of the heater and improves the thermal contact between the heater wire and the heater supports. After the wire had been wrapped around the core heater, it was covered with Zircar cement, which provides electrical insulation and increases thermal conduction from the heater wire to the heater supports.

Finally, a flat temperature zone was created on the quartz envelope's top surface by forming a hollow chamber at the top of the core heater. The heater then touches the BN top only at its perimeter. Thus, heat is conducted efficiently from the heater to the perimeter of the BN top, and inefficiently from the hotter central section of the heater to the center of the BN top. The balancing of efficient and inefficient heat conduction paths from the heater to the BN top yields a flat temperature zone on almost all of the top surface of the quartz envelope.

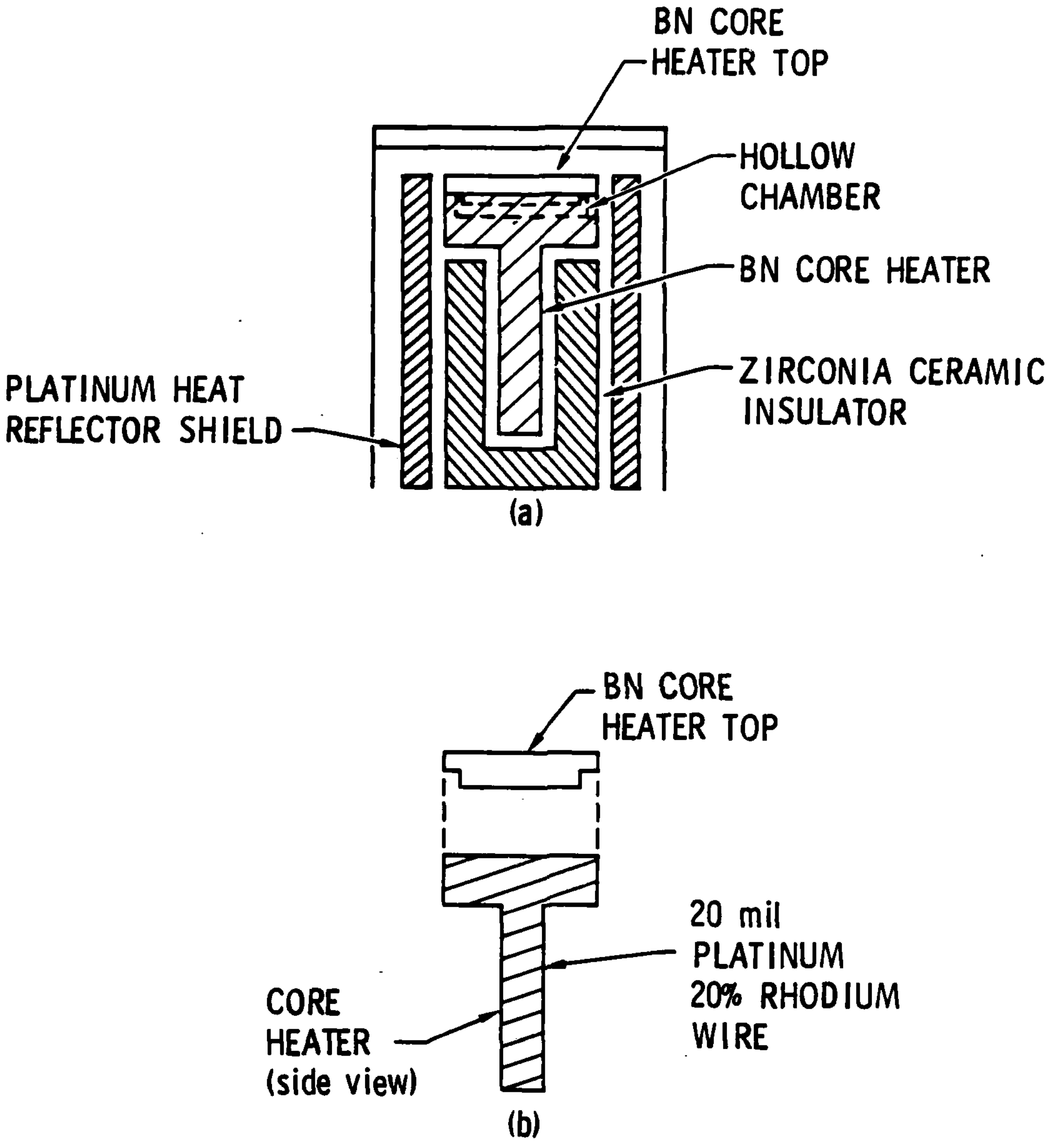

Figure 1. Quartz envelope heater: (a) internal structure; and (b) BN core heater and top, detailing winding.

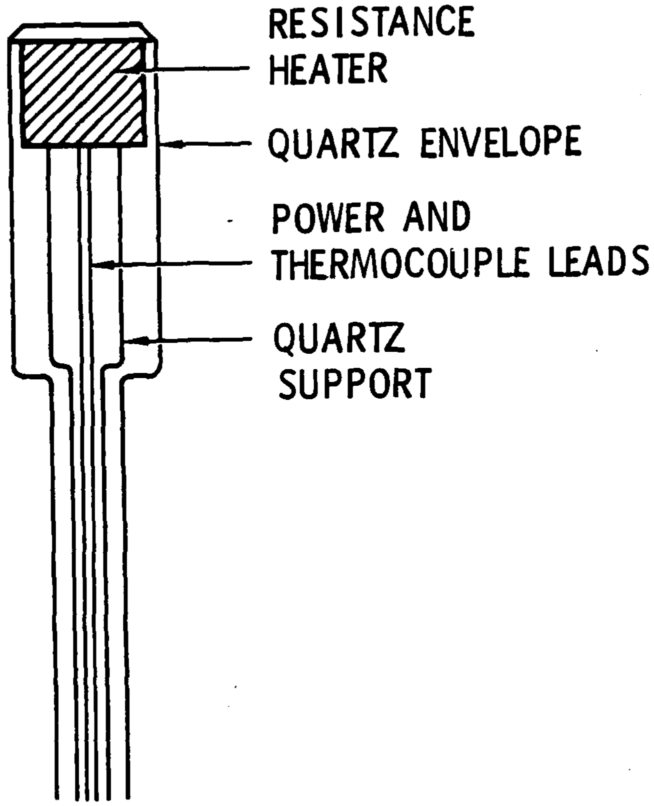

Figure 2. Details of quartz envelope heater assembly.

The operation of the quartz envelope heater was calibrated as follows. The top-surface temperature was measured simultaneously with that at the base of the core heater. The heater's top-surface temperature could then be set by adjusting the core temperature. The calibration was performed under conditions similar to those for growing epitaxial material. The heater was attached with a double O-ring seal to the base plate on which the reaction chamber is mounted. A silicon standard wafer was then mounted on the top surface of the quartz heater. The reaction chamber was affixed to the base plate and closed off with its top plate. The reaction chamber was then evacuated and filled with hydrogen gas flowing at the set rate of 5 standard liters per minute (SLPM). The core heater was powered with a Rubicon power controller, which in turn was controlled by a Barber Coleman 560 three-mode proportional controller.

The temperature of the heater's top surface was measured with an Ircon infrared pyrometer, which is sensitive to radiation between 2.0 and 2.6 μm. The Ircon measured the radiation from the highly polished silicon wafer placed on the heater's top surface. Silicon has a known emittance of 0.7 and serves here as a reference for optically measuring the surface temperature of actual GaAs wafers. The optical properties of the reaction chamber walls encasing the heater had to be considered in the measurement. The walls transmit only a fraction of the radiation emitted from the wafer. Therefore, the emittance was set on the Ircon pyrometer at 0.63, corresponding to a wall transmittance of 90 percent. A Pt/Pt-13% Rh thermocouple mounted in a recess at the core heater's base measured core temperature in degrees Celsius, using a Fluke digital thermocouple readout.

III. RESULTS

The curve of surface temperature versus core temperature measurements, presented in Figure 3, was generated by increasing the core temperature in increments and then measuring the stabilized surface temperature 5 min after the set point temperature had been reached. There was a small hysteresis in the surface temperature measurements when the core temperature was decreased. The discrepancy between ramping up and down disappeared after 30 min.

The curve in Figure 3 has linear high- and low-temperature regions separated by a "knee" at a core temperature of about 800°C. Radiative cooling is involved in the thermal balance of the heater and its surroundings in the high-temperature region--the significant portion for heater operation--but is of little importance in the low-temperature region.

The measurements indicate that the quartz envelope heater [illegible] heat a sample wafer to a temperature in excess of 700°C and maintain that temperature to within ±1.5°C. The temperature uniformity is about ±5°C within a 1-in.-diam circle centered on the heater's top surface.

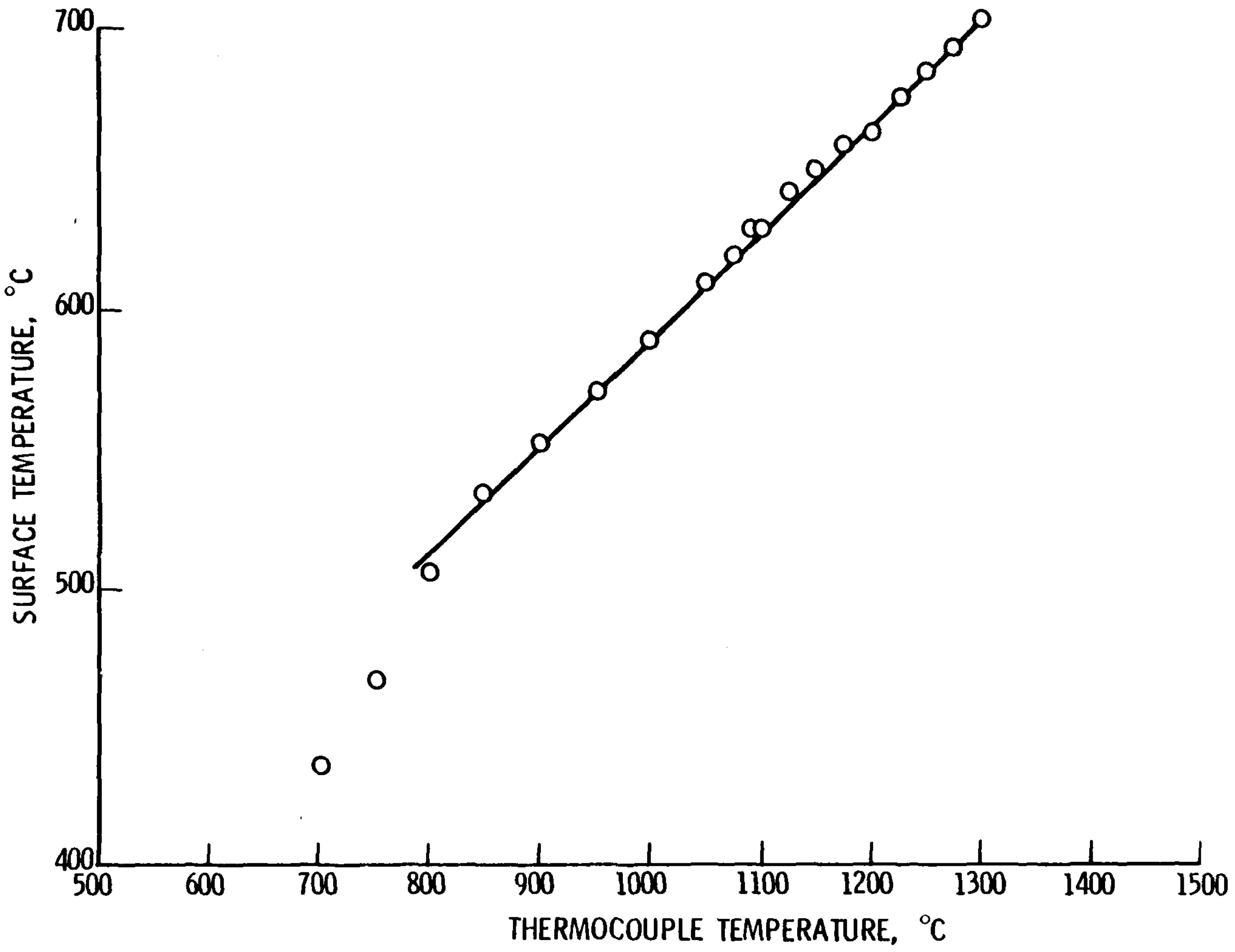

Figure 3. Surface temperature of quartz envelope heater versus temperature at core heater base. Surface temperature determined by Ircon infrared pyrometer with light emitted from silicon wafer; core temperature measured with Pt/Pt-13% Rh thermocouple.

IV. DISCUSSION

In RF heating, the standard process used in MOCVD epitaxial growth, a substrate is placed on a silicon-carbide (SiC)-coated carbon susceptor, which is set on a rotating quartz pedestal within a reaction chamber. An RF coil is then placed around the chamber. When activated, the coil couples energy into the susceptor and heats it. RF heating has the following drawbacks: (1) the RF generator is bulky and expensive (>$5000); (2) the induction coil must be designed specially to heat effectively and uniformly; (3) the sample must be rotated to even out temperature nonuniformity; and (4) the carbon susceptor must be sealed properly with a SiC coating to prevent the epitaxial growth and substrate from being contaminated by the carbon susceptor.

In quartz lamp heating, a lamp is placed at one focus of an elliptical mirror and a sample at the other. More than one lamp is generally used to attain the 700°C required for MOCVD epitaxial growth. The problems with this method are more serious than those associated with RF heating. The lamps, their housings, and the elliptical mirrors are outside the chamber. During an experiment, the quartz chamber walls cloud with reaction products; consequently, heating efficiency is reduced, and the temperature of the substrate decreases during the experiment. The resulting variation in growth temperature leads to variations in doping concentration and mobility through the layer.

The problems described above are avoided entirely with the quartz envelope heater. The heater does not contaminate the epitaxial material or the substrate. It is easily cleaned after each experiment. Its large, constant-temperature surface maintains its heating characteristics and calibration over a long period of time (e.g., heaters have been used for longer than 8 months or 30 experiments). The heater is easy to scale up for larger wafers, and is easy and inexpensive to construct. These properties of the quartz envelope heater make it completely superior to lamp systems and superior to RF systems in cost, simplicity of operation, and reproducibility.

V. CONCLUSIONS

The quartz envelope heater is a new apparatus developed at The Aerospace Corporation for use with an MOCVD system. It is easy and inexpensive to construct and can be scaled up or down to handle a variety of wafer sizes for MOCVD epitaxial growth. Use of resistance heating simplifies structure and facilitates heater operation and control.

Advantages of the new heater over RF and quartz lamp heaters that make it attractive for use in MOCVD systems are tighter temperature control and more uniform temperatures. Given these advantages, the new heater is expected to produce better epitaxial material. The quartz envelope heater can also be used in other chemical vapor deposition systems which require a single temperature zone of up to approximately 800°C and which do not contain reactants that chemically attack quartz glass.

The quartz envelope heater has been used at Aerospace over the past eight months in an MOCVD system for the growth of GaAs. Results obtained have been comparable to those from other MOCVD systems that employ traditional heating techniques.

LABORATORY OPERATIONS

The Laboratory Operations of The Aerospace Corporation is conducting experimental and theoretical investigations necessary for the evaluation and application of scientific advances to new military space systems. Versatility and flexibility have been developed to a high degree by the laboratory personnel in dealing with the many problems encountered in the nation's rapidly developing space systems. Expertise in the latest scientific developments is vital to the accomplishment of tasks related to these problems. The laboratories that contribute to this research are:

Aerophysics Laboratory: Launch vehicle and reentry aerodynamics and heat transfer, propulsion chemistry and fluid mechanics, structural mechanics, flight dynamics; high-temperature thermomechanics, gas kinetics and radiation; research in environmental chemistry and contamination; cw and pulsed chemical laser development including chemical kinetics, spectroscopy, optical resonators and beam pointing, atmospheric propagation, laser effects and countermeasures.

Chemistry and Physics Laboratory: Atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiation transport in rocket plumes, applied laser spectroscopy, laser chemistry, battery electrochemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, thermionic emission, photosensitive materials and detectors, atomic frequency standards, and bioenvironmental research and monitoring.

Electronics Research Laboratory: Microelectronics, GaAs low-noise and power devices, semiconductor lasers, electromagnetic and optical propagation phenomena, quantum electronics, laser communications, lidar, and electro-optics; communication sciences, applied electronics, semiconductor crystal and device physics, radiometric imaging; millimeter-wave and microwave technology.

Information Sciences Research Office: Program verification, program translation, performance-sensitive system design, distributed architectures for spaceborne computers, fault-tolerant computer systems, artificial intelligence, and microelectronics applications.

Materials Sciences Laboratory: Development of new materials: metal matrix composites, polymers, and new forms of carbon; component failure analysis and reliability; fracture mechanics and stress corrosion; evaluation of materials in space environment; materials performance in space transportation systems; analysis of systems vulnerability and survivability in enemy-induced environments.

Space Sciences Laboratory: Atmospheric and ionospheric physics, radiation from the atmosphere, density and composition of the upper atmosphere, aurorae and airglow; magnetospheric physics, cosmic rays, generation and propagation of plasma waves in the magnetosphere; solar physics, infrared astronomy; the effects of nuclear explosions, magnetic storms, and solar activity on the earth's atmosphere, ionosphere, and magnetosphere; the effects of optical, electromagnetic, and particulate radiations in space on space systems.

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