Advances in Thin Film Sensor Technologies for Engine Applications

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FOR ENGINE APPLICATIONS

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ABSTRACT

Advanced thin film sensor techniques that can provide accurate surface strain and temperature measurements are being developed at NASA Lewis Research Center. These sensors are needed to provide minimally intrusive characterization of advanced materials (such as ceramics and composites) and structures (such as components for Space Shuttle Main Engine, High Speed Civil Transport, Advanced Subsonic Transports and General Aviation Aircraft) in hostile, high-temperature environments, and for validation of design codes. This paper presents two advanced thin film sensor technologies: strain gauges and thermocouples. These sensors are sputter deposited directly onto the test articles and are only a few micrometers thick; the surface of the test article is not structurally altered and there is minimal disturbance of the gas flow over the surface. The strain gauges are palladium-13% chromium based and the thermocouples are platinum-13% rhodium vs. platinum. The fabrication techniques of these thin film sensors in a class 1000 cleanroom at the NASA Lewis Research Center are described. Their demonstration on a variety of engine materials, including superalloys, ceramics and advanced ceramic matrix composites, in several hostile, high-temperature test environments are discussed.

INTRODUCTION

In order to meet the urgent needs in aeronautic and aerospace research where stress and temperature gradients are high and aerodynamic effects need to be minimized, sensors in a thin film form are being developed at the NASA Lewis Research Center (LeRC) for surface measurement on various material systems. Sensors in a thin film form provide a minimally intrusive means of measuring surface parameters, such as strain or temperature, in hostile environments. They are needed in engine systems to evaluate advanced materials and components and to provide experimental verification of computational models. Unlike more conventional wire or foil sensors, thin films sensors do not necessitate any machining of the surface, thereby leaving intact the surfaces structural integrity. They are sputter deposited directly onto the surface and have thickness on the order of a few micrometers (μm) which are many orders of magnitude thinner than wire. Thin film sensors, therefore, add negligible mass to the surface and create minimal disturbance of the gas flow over the surface. Consequently, thin film sensors have minimal impact on the thermal, strain and vibration patterns that exist in the operating environment.

The thin film thermocouple (TFTC) technology was originally developed for application to superalloys used in jet aircraft engine for temperature measurements up to 1000 °C (Grant et al., 1981, Kreider et al., 1984). This technology was advanced through several NASA contracts and grants and extended to ceramic and intermetallic materials (Budhani et al., 1986, Holanda, 1992) used in the advanced jet engines. The work to develop and apply TFTCs at LeRC has been concentrated on platinum-13% rhodium (Pt13Rh) vs. platinum (Pt) due to its high temperature capability. They have been applied to silicon nitride, silicon carbide, aluminum oxide (alumina), mullite, ceramic matrix composites, space shuttle thermal protection system tiles, and nickel aluminide in the temperature range from 1000-1500 °C (Holanda, 1992, Holanda et al., 1993, Martin and Holanda, 1994, Martin and Will, 1996). TFTCs have undergone furnace tests as well as tests in harsh environments, including gas turbine (Grant et al., 1981) and hydrogen/oxygen engine environments under both low and high pressure conditions (Martin and Holanda, 1994), a high heat flux facility (Holanda, 1992, Holanda et al., 1993), and a diesel engine environment (Kim and Barrows, 1988).

Thin film strain gauge (TFSG) made of NiCr have been used successfully to 600 °C in gas turbine engines and component rig dynamic strain testing (Grant et al. 1983, Stowell and Weise, 1983). The strain gauges developed at NASA LeRC are based on a newly developed alloy,

palladium-13wt%chromium (hereafter, PdCr). This PdCr alloy was selected by United Technologies Research Center under a NASA contractto be the best candidate material for the high temperature strain gauge application (Hulse et al., 1987). It is structurally stable up to elevated temperatures and its apparent strain versus temperature characteristic is linear, repeatable and not sensitive to the rates of heating and cooling. Active development based on this new gauge alloy, PdCr, is being pursued to extend its use in both dynamic and static strain testing on superalloy, ceramic and CMC components of engines and aircraft structures to 1100 °C (Hulse et al., 1987, Lei, 1992, Kayser et al., 1992, Lei, 1995).

This paper describes efforts in the Sensors and Electronics Technology Branch of NASA LeRC in developing thin film strain gauges and thermocouples for high temperature applications on a range of materials. Sensor preparation techniques and procedures including thin film sputtering-deposition, electron beam evaporation, masking, and lead wire attachment techniques are discussed. The characteristics of the sensors and their testing results on various materials and in various environments are presented.

SENSOR FABRICATION

The fabrication of the thin film sensors is completed in a clean room to minimize possible contamination. The class 1000 cleanroom at the LeRC contains state-of-the-art facility including several thin film sputter-deposition and evaporation systems, wire bonding systems, etching systems, equipment for photolithography processes, and a surface profiler. The fabrication process of thin film sensor systems on a particular substrate material needs to be tailored to ensure good adhesion and no chemical interaction between the sensor and the substrate material. Figure 1 shows a schematic diagram of the thin film sensor layer structures on both electrically insulating and electrically conducting substrates. For an electrically conductive metal substrate, such as superalloy materials, an MCrAlY coating is first deposited onto the substrate by electron beam evaporation or by sputter deposition. M can represent Fe, Co, Ni, or a combination of Co and Ni. With heat treatment, this coating forms a stable, adherent, electrically insulating alumina layer. An additional layer of alumina is sputter deposited or electron beam evaporated onto the surface to fill any pinholes or cracks that may be present in the grown oxide. Electrically conductive ceramic materials such as silicon carbide are thermally oxidized to form a stable, adherent silicon dioxide layer which is followed by another layer of alumina of the thickness needed to obtain the required insulation resistance. The thickness of the thermally grown oxide and sputter deposited alumina layers are approximately 2-3μm and 5-8 μm, respectively. The sensors are fabricated onto the alumina layer; in the case of electrically insulating materials such as silicon nitride, aluminum oxide and mullite, the sensor are fabricated directly onto its surface. For

those applications that require a protective overcoat, a coating of alumina is deposited either by sputtering or evaporation onto the sensor to a thickness of approximately 2-3 μm.

Basecoat and Overcoat

Alumina is used as both the basecoat and overcoat for thin film sensor systems because it has the highest resistivity among all the dielectric materials. When deposited from a pure alumina source (99.9%), an insulating alumina thin film has an electrical resistivity as high as that of the bulk materials (5×10^7 ohm-cm at 1100 °C). For a 120 ohm strain gauge to be useable to 1100 °C, an alumina basecoat with a thickness of 7 μm or higher is needed to provide at least 0.1 Mohm resistance-to-ground at all operating temperatures up to 1100 °C.
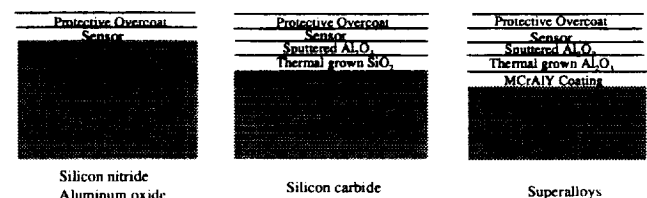

Silicon nitride
Aluminum oxide
Mullite

Silicon carbide

Superalloys

Figure 1. Schematic diagram of thin film sensors on various substrate materials.

To fabricate a dense and thick alumina layer with no pinholes or cracks, the substrate needs to be heated during sputtering to increase mobility of the depositing atoms and to minimize thermal stress. The alumina film is, therefore in extension during the deposition, and then in compression at room temperature with a level of stress high enough to compensate any expansion during use to the maximum temperature. It was found that 800-900 °C is the preferred substrate temperature range for depositing an alumina layer that is useful up to 1100 °C (Kayser et al., 1992). This alumina film can be put down by either sputtering or evaporation. The sputtering process is very slow, taking approximately 50 hours to prepare a 6-8 μm thick alumina film compared to only 20 minutes needed for the E-beam evaporation. The fabrication parameters for alumina films are listed in Table I.

Thermocouples

The thermocouples are patterned with stenciled shadow masks during sputter deposition of the Pt and Pt13Rh thin films. An adjacent heater is maintained at 400 °C during the sputter-deposition process. The sputtering parameters for 5 μm thick Pt and Pt13Rh films are listed in Table I.

Table I. Thin film deposition conditions for Pt13Rh/Pt thermocouples (TC) and PdCr/Pt strain gauge (SG)

MATERIAL	TARGET COMPOSITION	POWER DENSITY (W CM^{2})	DEPOSITION MODE	SUBSTRATE TEMP.	THICKNESS (μM)
Pt (TC &SG)	Pt	1.94	Magnetron	400 °C	5
Pt-Rh (TC)	Pt13wt%Rh	1.94	Magnetron	400 °C	5
PdCr (SG)	Pd14wt%Cr	1.94	Diode	25 °C	8
Alumina	Al_2O_3	3.44	R.F.	900 °C	6-8
Alumina	Al_2O_3	E-beam	Evaporation	900°C	6-8

Strain Gauge

Figure 2a presents a dynamic strain gauge made of a PdCr thin film. The PdCr gauge is prepared first by sputter deposition of PdCr thin film of approximately 8 μm thickness, then patterned using the photolithography technique and chemical etching with $FeCl_3$. For static strain applications, a temperature compensator element platinum (Pt) is adopted to minimize the temperature effect on the resistance change of the PdCr. This is because PdCr has a higher (but constant) temperature coefficient of resistance than that allowed for a static strain gauge. The Pt element, 5 μm thick, is located around the PdCr gauge grid and is connected to the adjacent arm of a Wheatstone bridge circuit to minimize the temperature effect (Lei et al., 1991) (Fig. 2b). The Pt compensator is patterned using a metal shadow mask during deposition. The sputtering parameters for both PdCr and Pt films are listed in Table I.
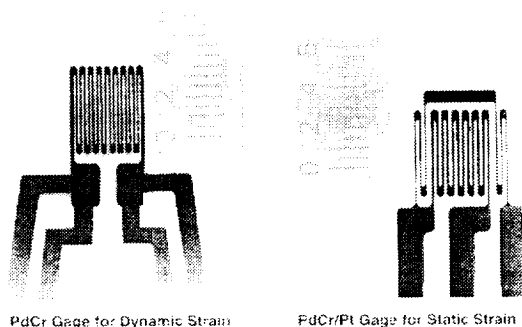

PdCr Gage for Dynamic Strain   PdCr/Pt Gage for Static Strain

Figure 2. PdCr based thin film strain gauges. (a) dynamic strain gauge and (b) static strain gauge.

Lead wire attachment

The 75 μm diameter leadwires which connect to the measurement circuits are attached to the thin films via the parallel gap welding process (Holanda et al., 1990). Leadwires made of Pt13Rh and Pt are used for Pt13Rh and Pt TFTC elements, respectively, and Pt leadwires are used for both PdCr and Pt strain gauge elements. The leadwires are secured onto the substrate by means of a high temperature ceramic cement.

SENSOR CHARACTERISTICS AND TESTING

Thermocouples

TFTCs have been fabricated and tested on various substrate systems including nickel based superalloys, silicon nitride (Si_3N_4), silicon carbide (SiC), mullite and aluminum oxide (Al_2O_3) ceramics, ceramic matrix composites (CMC), and intermetallics. The test conditions are summarized in Table II.

TFTCs on a nickel based superalloy have been tested up to 1100 °C in conditions similar to, though not as severe as, the Space Shuttle Main Engine (SSME) high pressure fuel turbopump environment (Martin and Holanda, 1994). Sensors tested on flat panels at low pressure conditions proved to be highly adherent and durable. However, when TFTCs were tested on SSME turbine blades, Fig. 3, under high pressure, high temperature conditions, repeated stable thermal output was difficult to obtain. This may be attributed to poor contact between the thin films and leadwires. The TFTC output was unstable during changes in pressure; the vibrations of the facility during start up and shut down may have also disrupted contacts between the wire and film thereby resulting in unstable output.
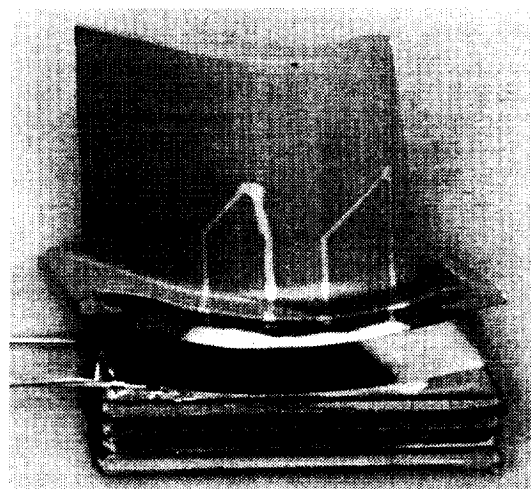

Figure 3. Pt13Rh/Pt Thin film thermocouples applied on space shuttle main engine turbine blade.

Table II. Summary of TFTC applications at NASA LeRC

MATERIAL	GEOMETRY	TEST CONDITION	TEMPERATURE - TIME
Nickel-based superalloy	flat plate	Hydrogen-oxygen combustion pressures to 4 MPa, atmosphere	0 to 900-1000°C in five seconds, ten cycles
Nickel-based superalloy	turbine blades	SSME type conditions; Hydrogen-oxygen combustion pressures to 16 MPa	0 to 930 °C in six seconds, three cycles
Al_2O_3 & Mullite	flat plate	air furnace	1000-1500 °C, 150 hrs static and cycling test & up to 2500 °C/sec thermal shock-20 cycles
Si_3N_4 & SiC	flat plate	air furnace	1000-1500 °C, 150 hrs static and cycling & up to 2500 °C/sec thermal shock-20 cycles
HPZ/SiC CMC	hoop	burner rig with jet fuel pressure to 2 MPa	gas temp: 1500 °C surface temp: 1100 °C, 25hrs
SiC/SiC CMC	flat plat & cylinder	burner rig with jet fuel pressure to 2 MPa	gas temp: 1500 °C surface temp: 1100 °C, 10hrs

The TFTCs instrumented on ceramic materials were evaluated in ceramic tube air furnaces under steady state and thermal cycling modes up to 1000 to 1500 °C for times up to 150 hours at ambient pressures (Holanda, 1992, Holanda et al., 1993). No sensor failures occurred during this total test time. The resulting drift rate of the TFTCs varies with: (1) the absolute temperature level of the substrate material on which the TFTC is deposited; (2) the temperature gradient distribution between the thin film and the leadwire portion of the circuit; and (3) the film thickness and diameter of the leadwires. At temperatures greater than about 1250 °C, drift rates rapidly increase as test temperature increases but varies for each substrate material. Selected drift rates of TFTCs on various materials and compared to that of wire TCs are tabulated in Fig. 4. The aluminum oxide and mullite had little visible surface deterioration after the tests, and there was very little degradation of the sensor structure. Silicon nitride and silicon carbide, however, exhibited visible surface changes at temperatures above about 1250 °C. The higher purity of these silicon-based materials reduced the amount of substrate surface oxidation and interfacial reactions that can contribute to sensor failure. TFTCs on silicon nitride and mullite also exhibited good durability to survive a 20 cycle test with a heating rate up to 2500 °C/sec (Holanda et al., 1993).
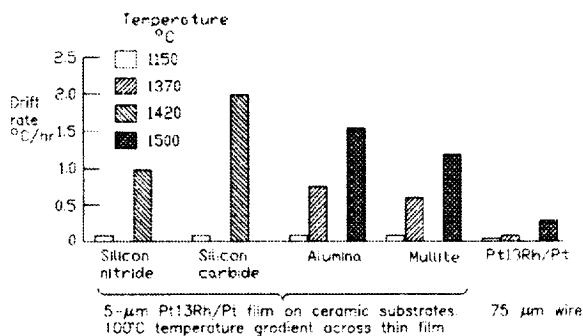

Figure 4. Drift rates for thin film thermocouples compared to that of wire thermocouples.

More recent applications of TFTCs have been concentrated on the evaluation of advanced CMC materials (Martin and Will, 1996) designed to meet propulsion capability goals of the Integrated High Performance Turbine Engine Technology (IHPTET) and High Speed Civil Transport (HSCT). A hoop made of hydridopolysilazane fiber/silicon carbide

(HPZ/SiC) CMC was instrumented with three TFTCs and tested in a burner rig that operates on jet fuel at pressure of 0.7 to 2 MPa (100-300 psi). The average gas stream temperature is approximately 1500 °C. A TFTC provided surface temperature data up to 1100 °C for over 25 hours. The eventual failure mechanism for the TFTCs was again due to the poor contacts between the thin film and the leadwires as well as the leadwires attachment on the CMC substrate material. Several SiC/SiC CMC flat panels and cylinders are being instrumented with TFTCs and tested in the same facility. Improvements in the lead wire attachment technique are being addressed.

Strain Gauges

The advanced PdCr based TFSG is a much newer technology compared to the Pt13Rh/Pt TFTCs. Their applications in harsh environments have therefore been limited. They, however, have been fabricated and tested on various substrate systems including nickel-based superalloys, silicon nitride (Si_3N_4) and aluminum oxide (Al_2O_3) ceramics, and SiC/SiC ceramic matrix composites (CMC). The test conditions are summarized in Table III.

Depending on the application, whether for dynamic strain or static strain measurement, the requirements for a useful gauge may be different. For dynamic strain measurements during which the rate of change in strain is much larger compared with the rate of change in temperature even if the time period is long, the allowed apparent strain sensitivity of a gauge can be very high. The general requirements for a useful dynamic strain gauge are (1) its apparent strain sensitivity is less than 100 microstrain ($\mu\epsilon$)/°C, and (2) its drift strain rate at use temperatures is less than 500 $\mu\epsilon$/hour (Grant et al., 1983). On the other hand, for static strain measurement over long periods of time during which both the temperature and strain may vary, the allowed apparent strain and drift strain of a useful gauge are much lower than that for a dynamic strain gauge. For a required accuracy of 10% for static strain measurements in the range of 2000$\mu\epsilon$, the total apparent strain and the drift strain should be smaller than 200 $\mu\epsilon$, so as to be neglected, or repeatable within 200 $\mu\epsilon$, so it can be corrected.

When connected to a Wheatstone bridge circuit in a quarter bridge configuration, the resulting apparent strain of a PdCr dynamic strain gauge is stable and repeatable between thermal cycles to 1100 °C (Lei, 1995). The apparent strain sensitivity is approximately 85 $\mu\epsilon$/°C which is less than the required value of 100 $\mu\epsilon$/°C. The drift strain of the gauge at 1100 °C is also less than the required value of 500 $\mu\epsilon$/hour. The resulting apparent strain characteristic of a PdCr static strain gauge connected to a

Table III. Summary of TFSG application at NASA LeRC

MATERIAL	GEOMETRY	TEST CONDITION	TEMP-TIME
Nickel-based superalloy	cantilever bar &125 µm shim	air furnace & heat flux arc lamp	up to 1100 °C & up to 1000 °C/sec thermal shock
Al_2O_3	cantilever bar	air furnace & heat flux arc lamp	up to 1100 °C & up to 1000 °C/sec thermal shock
Si_3N_4	flat plate & turbine blade	air furnace and spin rig	up to 1100 °C, static and cycling under ±2000µɛ
SiC/SiC CMC	flat panel	burner rig with jet fuel pressure to 2 MPa	gas temp: 1500 °C, surface temp: 1100 °C

Wheatstone bridge circuit in a half bridge configuration is stable and repeatable within 200 με between thermal cycles to 1100 °C with a sensitivity less than 3.5 με/ °C in the entire temperature range. The apparent strain of this PdCr compensated thin film gauge can be corrected to within 200με if the uncertainty in temperature measurement is within 57 °C. This PdCr based gauge is stable and responds linearly to the mechanical loads even at 1050 °C. Its strain sensitivity (or gauge factor) decreases only approximately 22% from room temperature to 1050 °C (1900 °F) (Fig. 5).
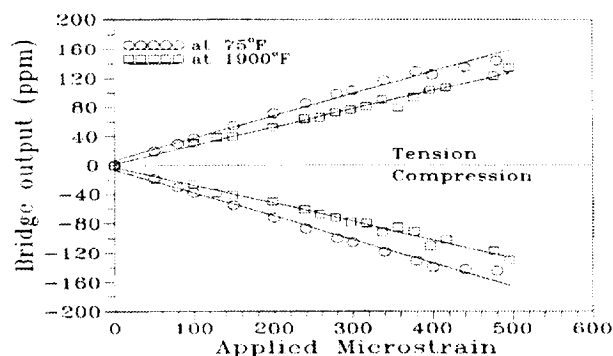

Figure 5. Mechanical response of a PdCr based strain gauge at both room temperature and at 1050 °C (1900 °F).

PdCr based TFSGs have been evaluated on various materials in the air furnace up to 1100 °C and in a heat flux calibrator with high heating rates up to 1100 °C/sec. Heat flux lamp currents from 30 to 400 amp are used to generate heat fluxes from about 0.1 to 2 MW/m^2 and a heating rates from about 2 to 1100 °C/sec. Maximum temperature was 1100 °C. No sensor failures occurred after they were subjected to the maximum heat flux. These advanced PdCr dynamic gauges were also applied to an advanced turbine blade made of silicon nitride utilized in the IHPTET environment (Fig. 6). The gauge survive tests up to a maximum speed of 42500 rpm and a fatigue tests under ±2000 με up to 1000 °C for a million cycles. The gauges are now being applied to SiC/SiC CMCs components for HSCT and evaluated in a burner that operates on jet fuel at pressure of 0.7 to 2 MPa (100-300 psi). The average gas stream temperature was approximately 1500 °C, and the CMC surface temperature was approximately 1100 °C.

A weldable PdCr based TFSG was also developed by first fabricating the gauge on a metal shim, which is then transported and welded on the test article. It provides an option for applications where sputtering a gauge directly on a large test article is impossible or the installation of the gauges has to be done in the test field. A metal shim such as a 75μm thick Hastelloy-X should have a similar CTE to that of the substrate material. The apparent strain curve of a weldable gauge is similar to that of the gauge deposited directly on the substrate. The mechanical response of this weldable gauge is also similar to that of a directly-deposited gauge in that it is linear to the mechanical load and has no delay in transferring the strain (Lei, 1995).
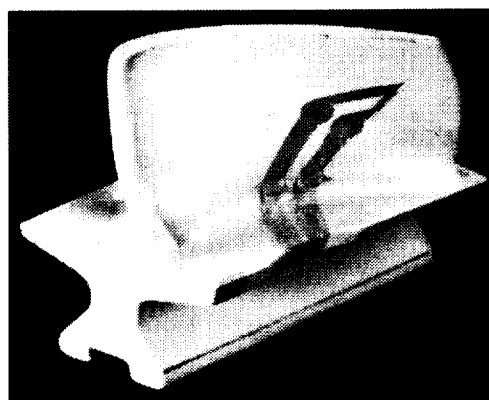

Figure 6. PdCr thin film dynamic strain gauge applied on a silicon nitride turbine blade[1].

SUMMARY AND FUTURE WORK

Measurement techniques for propulsion systems are advanced through the development of thin film thermocouples and strain gauges. These thin film sensors have the advantage of providing minimally intrusive measurements. Thin film thermocouples, made of Pt13Rh/Pt, have proven to be applicable to a range of materials and applications. They have been demonstrated on superalloys, ceramics, ceramic composites, and intermetallics. Data has been obtained in furnace testing, under high heat flux conditions, and in harsh engine environments. Thin film strain gauges based on a newly developed alloy, PdCr, have been developed for both dynamic and static strain applications in the temperature range from room temperature to 1100 °C. This is a 500 °C advance over the more conventional NiCr technology. A weldable strain gauge for applications where sputtering a gauge directly onto a large test article is impossible or the installation of the gauges has to been done in the test field has also been developed.

Future work will be concentrated on the improvements of the reliability and durability of these sensors in the high temperature, high pressure, high velocity gas stream environments. The lead wire attachment techniques to both the thin films and the substrate materials needs to be improved. A more protective coating to protect thin film sensors from erosion and catalytic reactions in these environments will also need to be addressed. The gaging techniques on the curved surface is an area of further investigation. Characterization of these thin film sensors on advanced materials such as CMCs will continue in order to establish a statistical database. In addition, the next generation of sensors that can be used to even higher temperatures (>1200°C) will be explored to address the needs for advanced aeropropulsion research.

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REFERENCES

Budhani, R. C., Prakash, S. and Bunshah, R. F., 1986, "Thin Film Temperature Sensors for Gas Turbine Engines; Problems and Prospects", J. Vac. Sci. Technol. A, vol. 4, pp. 2609-2617, Nov.-Dec.

Grant, H. P., Przybyszewski, J. S. and Claing, R. G., 1981, "Turbine Blade Temperature Measurements Using Thin Film Temperature Sensors", PWA-5604-31, NASA CR-165201.

Grant, H. P., Przybyzewski, J. S., Anderson, W. L. and Claing, R. G., 1983,"Thin Film Strain Gauge Development Program", NASA CR-174707.

Kayser, P., Godefroy, J. C., and Leca, L., 1992, "High Temperature Thin Film Strain Gauges", Eurosensors VI Conference Proceeding, October.

Kreider, K. G., Semancik, S., and Olson, C., 1984, "Advanced Thin Film Thermocouples", NBSIR 84-2949, National Bureau of Standards, NASA CR-175541.

Kim, S., and Barrows, R. F., 1988, "Prototype Thin Film Thermocouple/Heat Flux Sensor for a Ceramic-Insulated Diesel Engine", DOE/NASA/50162-1, NASA TM-100798.

Holanda, R., Kim, W. S., Pencil, E., Groth, M., and Danzey, G., 1990, "Attachment of Lead Wires to Thin Film Thermocouples Mounted on High Temperature Materials Using the Parallel Gap Welding Process", NASA TM-102442.

Holanda, R., Anderson, R. C., and Liebert, C. H., 1993,"Heat Flux Measurements on Ceramics with Thin Film Thermocouples", SEM Fall Conference Proceeding of Structural Testing Technology at High Temperature, p.78-87.

Holanda, R. ,1992, "Development of Thin Film Thermocouples on Ceramic Materials for Advanced Propulsion System Applications", 7th International Symposium on Temperature: Its Measurement and Control in Science and Industry, Toronto, Canada, April.

Hulse, C. O., Bailey, R. S., Grant, H.P., and Przybyzewski, J. S., 1987, "Development of a High Temperature Thin Film Static Strain Gauge", NASA CP-2493.

Lei, J. -F, Englund, D. R., and Croom, C., 1991, "The Temperature Compensation Technique for a PdCr Resistance Strain Gauge", SEM Fall Conference for Structural Testing Technology at High Temperature Proceeding, P. 190-96.

Lei, J. -F., 1992, "TECH SPOTLIGHT- PdCr Gages Measure Static Strain at High Temperature", Advanced Materials & Processes, p.58-59, May.

Lei, J.-F., 1995, "High Temperature Thin film Strain Gauge", British Society for Strain Measurement 1995 Annual Conference Proceeding, p.13-16.

Martin, L. C., and Holanda, R., 1994, "Applications of Thin Film Thermocouples for Surface Temperature Measurement", NASA TM-106714.

Martin, L. C. and Will, H. A., 1996, "Testing of Thin Film Thermocouples on Ceramics Matrix Composites in a Burner Rig", NASP CP-10146 , Paper 39.

Stowell, W. R. and Weise, R., 1983, "Application of Thin film Strain Gauges and Thermocouples for Measurement on Aircraft Engine Parts", AIAA-83-1292, AIAA/SAE/ASME 19th Joint Propulsion Conference, Seattle, June.

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