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EDUCATION:

MBA	The Fuqua School of Business, Duke University, Durham, NC.
HSM Cert.	Duke Health Sector Management Certificate, Duke University, Durham, NC.
ME	Spl. in Manuf. Syst. Engg., University of Virginia, Charlottesville, VA.
Ph.D.	Indian Institute of Science, Bangalore, India.

PROVEN AREAS OF EXPERTISE INCLUDE:

- Reduced Risk Product Strategies
- Heat Source Product Development
- "Heat But Not Burn Product" Development
- Materials Science and Manufacturing
- R&D Management and Business Strategy
- Intellectual Property Rights and Strategies
- Corporate venture capital and private equity
- Innovation and innovation culture

RESEARCH and MANAGEMENT EXPERIENCE:

9/2013	-	Present	President, 4D Strategies, Midlothian, VA 23113. Strategy & Innovation Consultant.
12/2008	-	9/1/2013	DIRECTOR, IP Management and Altria Ventures Fund, Altria Group, Inc. VA
9/2005	-	12/2008	DIRECTOR, Global Innovation, Philip Morris USA, Richmond, VA
8/2004	-	9/2005	PROJECT DIRECTOR, Identification of New Businesses, Philip Morris USA, Richmond, VA
7/2003	-	7/2004	STRATEGIC PLANNER, Operations & Technology, Philip Morris USA, Richmond, VA.
5/2000	-	6/2003	SENIOR PRINCIPAL SCIENTIST, RD&E Center, Philip Morris USA, Richmond, VA.
3/1999	-	5/2000	PRINCIPAL SCIENTIST, RD&E Center, Philip Morris USA, Richmond, VA.
3/1998	-	3/1999	ASSOCIATE PRINCIPAL SCIENTIST, RD&E Center, Philip Morris USA, Richmond, VA.
12/1994	-	1/1995	VISITING ASSOCIATE, California Institute of Technology, Pasadena, CA.
6/1995	-	8/1995	VISITING SCIENTIST, University of Cambridge, Cambridge, England.
8/1994	-	1/1996	GUEST SCIENTIST, Oak Ridge National Laboratory, Oak Ridge, TN.
1/1994	-	8/1998	SENIOR RESEARCH SCIENTIST, RD&E Center, Philip Morris USA, Richmond, VA.
8/1988	-	1/1994	RESEARCH SCIENTIST, RD&E Center, Philip Morris USA, Richmond, VA.
10/1985	-	8/1988	SENIOR RESEARCH ENGINEER, University of California, Davis, CA.
5/1982	-	10/1985	RESEARCH ASSOCIATE in ENGINEERING, Brown University, Davis, CA.
8/1977	-	5/1981	*RESEARCH FELLOW*, Indian Institute of Science, Bangalore, India

Research Experience: Total Number of Google Citations is 14398 with an h-index of 54 and i10-index of 132.

Development of Reduced Risk Next Generation Products:

Instrumental in the strategy, development and execution of materials, processes, testing and validation required for reduced risk products at Philip Morris USA and Altria since the Programs started in 1988. Managed, directed and was responsible for the research, product development, manufacture, testing, reliability and quality assurance aspects as a Project Leader, Program Leader and as a Director.

Established a diverse research group and laboratory and managed the program with several millions of dollars' budget. Managed employees, post-docs, research associates, interns, co-ops, and contractors. Managed over 20 external research contracts at US National Laboratories and at US, Japan and European Universities.

Made presentations to the Chairman, Vice-Chairman, and to the top senior management of the corporation.

Responsible for the identification, evaluation, protection, and recommendation of intellectual property on "advanced materials and technologies" for "heated tobacco products". Managed and created a diverse a patent portfolio on reduced risk products with close to 200 US Patents alone.

The technology know-how, knowledge and the manufacturing aspects of "heated tobacco products" were transferred to Philip Morris International's R&D team and to their partners prior to spin off from Altria. It became the basis for Platform 1 and Platform 2 of PMI's Reduced Risk Portfolio.

Heated Tobacco Product based on "Heat Source Technologies":

- Led, conceived and developed materials for "heat sources" to generate and maintain heat like "lit-end cigarettes" without generating excessive amounts of harmful compounds and ash. The resulting product is a UNIQUE heat source with compounds where in 98% of the CO is oxidized and the heat source could be lighted with a match or with a lighter. The spent heat source provided a visual confirmation of the extinguishment of the heat generation.

- The heat source materials and processes developed in the laboratories were scaled up to a pilot plant and the pilot plant data was used to "design and build a large scale continuous manufacturing plant" to manufacture the PATENTED heat sources. Several hundred million heat sources were manufactured to assemble products with tobacco pellets and filters. Managed and directed the mixing, extrusion, debindering and decomposition, machining, and quality control operations of heat source manufacturing and proper functioning of "heated tobacco products" during and after assembly.

- The properties of the heat sources were optimized such that the tobacco pellets placed behind the heat source are optimally heated by conduction and convection mechanisms upon puffing. Exothermic reactions were controlled such that the smokers could use "heated tobacco product" under normal puffing conditions for at least 8 puffs. Extensive product testing has shown significant reduction in harmful and potentially harmful constituents of smoke as compared to traditional cigarettes – as measured by tar, gas and vapor phase constituents of aerosol.

Heated Tobacco Product based on "Electrical Heating Technologies":

A wide variety of technologies were conceived and explored starting in 1990 to develop a product solely based on heating of tobacco to a *desired temperature* without depending on the combustion processes of tobacco. This revolutionary concept required a heater, a means of controlling the

temperature, an energy source to heat and control the temperature of a heater, and a unique tobacco rod that can only be heated without burning (hence the concept – "heat but not burn" to generate flavorful and sensorially acceptable aerosol during the 2 to 4 sec puff interval.

The product development efforts progressed from heating eight individual heaters in a linear manner to a design where eight heaters can be individually heated with a common base.

- Developed "amorphous" carbon heaters using powder metallurgical principles with varying electrical resistivity's using phenol formaldehyde as the base material and as a binder. Electrical discharge machining was used to machine intricate carbon resistors with excellent quality to assemble linear electrical heaters into a linear electrically heated tobacco product using Ni-metal hydride as the battery. A thin film of gold was deposited to reduce the contact resistance.

- Developed a thermally efficient flat ceramic heater with a quick response time based on thick film technology using a substrate, resistor, and conductor using screen printing technology.

- Developed micro-heating elements using Phosphorous doped single crystal Si (100 plane) with a positive temperature coefficient of resistance to control the temperature rise during heating regime and to enable the use of pick and place equipment for the assembly of heaters.

- Carried out finite element thermal and electrical modelling to determine optimum heater design/s that can be heated eight times without burning tobacco present in an 8mm diameter tobacco rod. Extensive mathematical modeling efforts led to a design that can individually heat eight microheaters with minimal thermal, electrical, and energy losses.

- Manufacturing cost and speeds, matching of electrical resistivity to the energy source, and other parameters required exploration of a metallic heater that can come in contact with a tobacco rod. After extensive search and testing, Haynes 214 alloy (containing nickel and chromium) was selected as a heater material. To ensure protection from chromium present in the alloy, a thin layer of passive coating was developed on the Haynes 214 superalloy. This became the primary workhorse material to test the concept of a "heated tobacco product" and optimize the properties of a heater such that there is a significant reduction in harmful and potentially harmful products under acceptable sensory preferences of smokers. Heaters and electrically heated tobacco products were tested for 10,000 cycles under cyclic loading and unloading to determine the creep and life cycle times with and without a uniquely designed tobacco rod.

- As an alternate to the nickel and chromium based Haynes 214 alloy, electrically conducting high temperature ceramic composites based on molybdenum disilicide, silicon nitride, silicon carbide, and titanium carbide with varying resistivity's were developed by the application of percolation theory. The composites were characterized for their TCR, thermal conductivity, oxidation resistance, and cyclic failure. Composites were machined into intricate shapes and designs, and tested their function as high temperature sensors, and resistors. The study has been extended to develop functionally graded ceramic materials with conductive and resistive portions. The processes and products are unique, and received worldwide patents.

- Studied machinability of the materials using electrical discharge machining techniques, ultrasonic machining, and diamond cutting techniques to determine the cost effectiveness of machining from a systems and flexible manufacturing approach.

- Toxicity concerns associated with nickel and chromium elements in Haynes 214 led us to develop a new heater material exclusively based on alloys of iron and aluminum. Responsible for the alloy design, processing, characterization and development of high strength and creep resistant iron aluminides with exceptional oxidation resistance for use as a heater in "heated tobacco product". Led the strategy for manufacturing of heaters and assisted in integration of heaters into the manufacturing of electrically "heated tobacco product" in Japan.

- An innovative electrically heated tobacco product with the potential to "reduce population harm" was introduced under the brand name "Accord" in Japan and in USA. Toxicological testing by colleagues confirmed that controlled heating of tobacco as opposed to burning of tobacco does significantly reduce harmful and potentially harmful constituents paving the way to create "reduced risk products" and potentially "reduce the harm to the population" as may be noted from the following:

  - A reduction of 20% to 30% in total particulate matter (TPM) in the smoke.
  - A reduction of 50% to 60% in tar and nicotine in the smoke.
  - A reduction of at least 90% in CO, nitrogen oxides, 1,3-butadiene, isoprene, acrylonitrile, aromatic hydrocarbons, hydrogen cyanide, aromatic amines, NNK, and phenol.
  - A reduction of at least 96% in the in vitro mutagenicity of TPM (in the Salmonella mutagenicity test in strains TA98 and TA100 with metabolic activation).
  - An 80% to 85% reduction in the in-vitro mutagenicity of TPM from the in the mouse lymphoma thymidine kinase assay (with and without metabolic activation, respectively).
  - An 82% to 85% reduction in the in vitro cytotoxicity of the TPM fraction and a 65% to 66% reduction for the water-soluble portion of the gas-vapor phase in the neutral red uptake assay using BALB/c 3T3 cells.
  - Both short-term (8-day) and long-term (12-week) clinical studies were conducted to assess *human exposure to selected cigarette smoke constituents*. The assessments were performed by measuring validated biomarkers of smoke exposure in adult smokers of ACCORD when switched from commercially available, conventional cigarettes. Changes in biomarkers of exposure in smokers of ACCORD were assessed to determine the reduced-exposure potential and found that significant decreases were noted in short, and long term clinical studies with ACCORD as compared to conventional lit-end cigarettes.

- Led and participated in many different strategic R&D projects between Philip Morris/Altria Group, Inc. and Philip Morris International prior to the spin off. Led and managed IP activities between the companies as part of the 10-year agreement between ALCS of Altria Group, Inc. and spun off entity Philip Morris International.

- Received two R&D 100 AWARDS known as "Oscars of Invention".

- Recognized as a Member of the "Inventors Achievement Circle" in 1999, 11 years after joining the company. Listed as an inventor on 60 US Patents and over 150 international patents.

- Some of the US patents granted for the work on the "development of novel heated tobacco products" are listed below.

- Method of manufacturing aluminide sheet by thermomechanical processing of aluminide powders
- Functionally stepped, resistive ceramic
- Flavor generating article
- Electrical heater of an electrical smoking system
- Heater element of an electrical smoking article and method for making same
- Method of manufacturing an electrical heater
- Electrical smoking system for delivering flavors and method for making same
- Tubular heater for use in an electrical smoking article
- Iron aluminide useful as electrical resistance heating elements
- Flavor generating article and method for making same
- Aluminum containing iron-base alloys useful as electrical resistance heating elements
- Method for making a carbonaceous heat source containing metal oxide
- Electrically powered ceramic composite heater
- Heater having a multiple-layer ceramic substrate and method of fabrication
- Method for making a carbonaceous heat source containing metal oxide
- Chemical heat source comprising metal nitride, metal oxide and carbon
- Flat ceramic heater having discrete heating zones
- Electrical smoking system for delivering flavors and method for making same
- Reinforced carbon heater with discrete heating zones
- Heater for an electric flavor-generating article
- Method for producing metal carbide heat sources
- Catalytic conversion of carbon monoxide from carbonaceous heat sources
- Electrically-powered heating element
- Chemical heat source comprising metal nitride, metal oxide and carbon
- Composite heat source comprising metal carbide, metal nitride and metal
- Electrically-powered linear heating element

E-Vapor Products based on Heating of Liquid with Li-ion battery:

- Assisted in the development of an advanced e-vapor product with energy control, consistent characteristics of an aerosol, battery management system for Li-ion battery along with rapid charging features, puff control and overheating and short circuit protection. The features were optimized based on rigorous consumer validation.

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