NANOARMOR

Additively Manufactured Ultra-High Temperature Ceramics for Hypersonic Vehicles

The Race Is On…

"Emerging hypersonic technologies from Russia and China will markedly raise threats to regional balances and to our major allies and partners."

– United Stated 2019 Missile Defense Review

Hypersonic vehicles currently under development overseas are a major threat to US National Security

Conventional defensive strategies and technologies cannot keep up in this new hypersonic arms race

The Department of Defense contracting system is resorting to extreme measures, with over $2 billion in R&D funding for hypersonic vehicles to Lockheed Martin alone

Reliance on traditional legacy systems limits the development of exponential innovations that will be required to keep up with our adversaries

Environmental conditions experienced during hypersonic flight exceed the capabilities of most current state-of-the-art materials

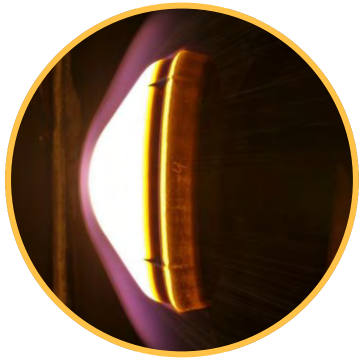
Extreme processing parameters and complex supply chains for high temperature materials dictate long lead times and are not cost effective

New advanced materials and novel efficient manufacturing processes must be investigated

Why Now?

“Hypersonic vehicle capabilities are the highest technical priority. ” – Michael Griffin, Pentagon Under Secretary of Defense for Research and Engineering

Adversarial hypersonic weapon capabilities are one of the leading current threats to US national security



Government R&D funding is increasing for high-temperature advanced materials and thermal protection systems

US lawmakers passed a law in 2019 requiring that hypersonic weapons be operational by 2020

DoD’s proposed budget through fiscal 2024 calls for upward of $10.5 billion in hypersonic weapons development

New aerodynamic shapes, never before conceived in the hypersonics realm, are being implemented that require extreme material capabilities

And now Nanoarmor has the patents, knowledge, technology, and ability to surpass current material requirements without the extreme processing and supply chain measures

Recent Programs and Funding

The 2021 unclassified defense spending request for hypersonic technology is already more than $3 billion, up more than $600 million from 2020

Army

- Dynetics wins $351M to build first missile for a combat unit (C-HGB)
- Lockheed wins $347M to develop Long Range Hypersonic Weapon (LRHW) launchers

DARPA

- Raytheon wins $200M to develop air-breathing cruise missile (HAWC)

USAF

- Lockheed wins $480M to develop Air-launched Rapid Response Weapon (ARRW)

NAVY

- Lockheed wins $846M to develop Conventional Prompt Strike (CPS) weapon

Recent Programs and Funding

“Within the DoD, there are currently 8-9 hypersonic weapon programs executing concurrently with most having the same goal of fielding a residual operational capability in the next 2-4 years.”

Program Name	Government Agency	Contract Awardee(s)	Contract Amount	Contract Timeline	Notes
Air-launched Rapid Response Weapon (ARRW)	USAF	Lockheed	$480M	Testing through 2022	Termed “Super-Duper Missile” by President Trump
Hypersonic Conventional Strike Weapon (HCSW)	USAF	Lockheed	$918M	Awarded 2018	Designed for aerial launch from B-52
Hypersonic Air-breathing Weapon Concept (HAWC)	USAF/DARPA	Lockheed/ Raytheon	$200M	Final program review in 2021	Jet-propelled hypersonic vehicle
Long-Range Hypersonic Weapon (LRHW)	Army	Lockheed	$347M	Testing through 2023	Long-range with ability to launch from ground mobile platforms
Common-Hypersonic Glide Body (C-HGB)	Army	Dynetics	$351M	Deploy 2023	Intended for land and submarine hypersonic launches
Tactical Boost Glide (TGB)	USAF/DARPA	Lockheed	$139M	Operational by 2023	Rocket-propelled hypersonic vehicle
Operational Fires (OpFires)	DARPA	Lockheed	$31.9M	Testing through 2022	Long range artillery and missiles
Advanced Full Range Engine (AFRE)	DARPA	Orbital ATK	$21.4M	Awarded 2017	Dual turbine/ramjet engine for low-speed and hypersonic
Intermediate Range Conventional Prompt Strike (IR CPS)	Navy	Lockheed	$846M	Awarded 2019	Shorter flight time and high survivability against defenses

The Problem

Exponential innovations in high temperature materials and a nimble supply chain are required for rapid development in hypersonic capabilities

BUT…

Conventional solutions have relied on decades-old materials, extreme processing parameters, and extensive resources

The Problem

Metal Superalloys

- Maximum operating temperature of ~1500˚C
- Not resistant to oxidation
- Difficult to homogenously disperse strengtheners and additives
- Material properties are heavily dependent on processing parameters
- Susceptible to creep
- Thermal expansion mismatch between bulk parts and protection coatings

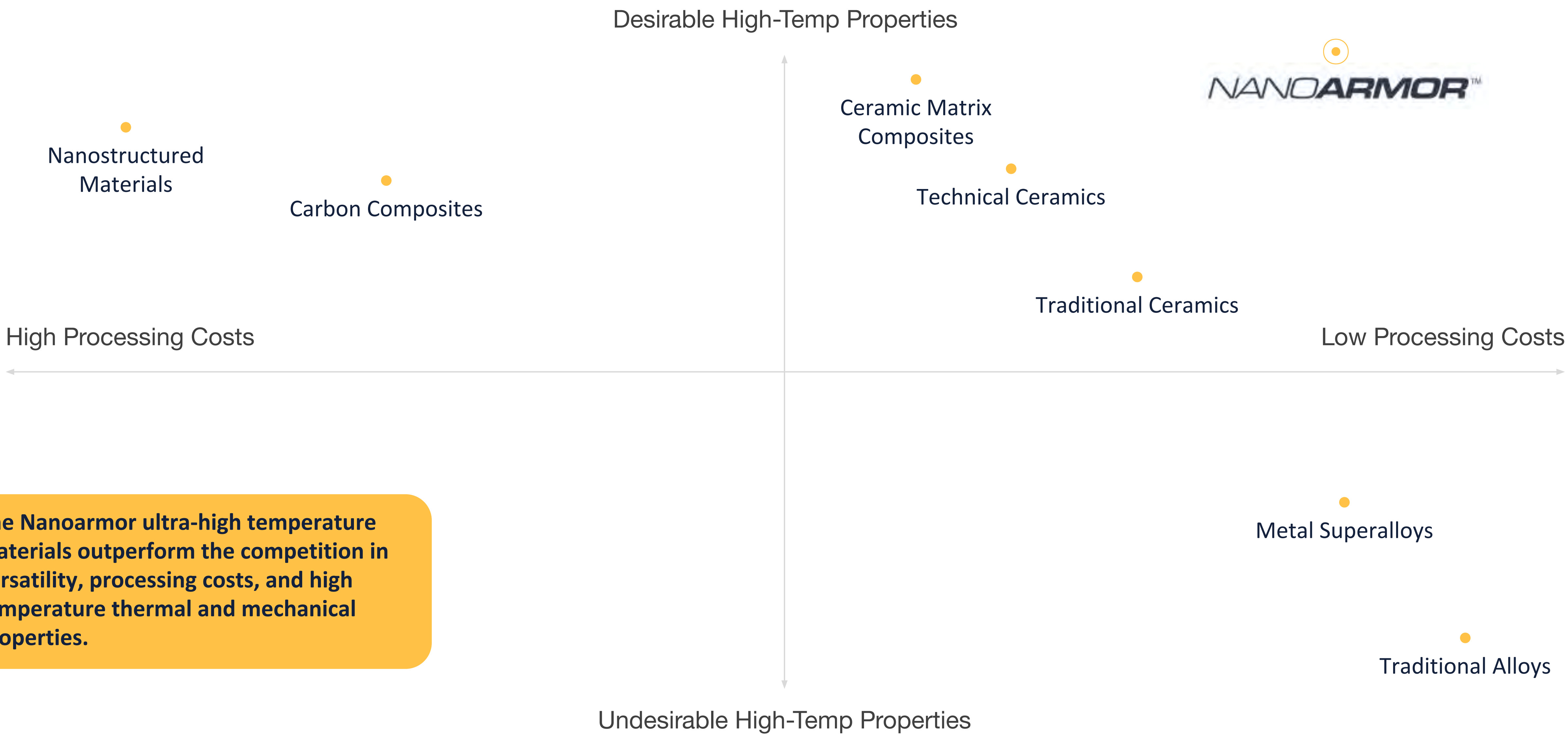
Carbon Composites

- Strict processing requirements that typically require many labor-intensive steps
- Not resistant to oxidation
- Carbon is an ablative material, meaning it consumes itself as it dissipates energy
- Continuous fibers don't allow for additive manufacturing technologies
- Susceptible to material erosion

Traditional Ceramics

- Highly brittle, low toughness materials that can suffer catastrophic failure modes
- Low thermal shock resistance
- Difficult to form net-shape parts of intricate geometries
- Very high temperature processing requirements for desired grain sizes
- Traditional polymer-derived synthesis approaches have very low char yield, which results in low densities and more defects

Competitive Advantage



The Nanoarmor ultra-high temperature materials outperform the competition in versatility, processing costs, and high temperature thermal and mechanical properties.

The Solution

Newly developed ultra-high temperature materials in Nanoarmor's IP portfolio have simplified processing requirements while maintaining integrity in extreme hypersonic conditions

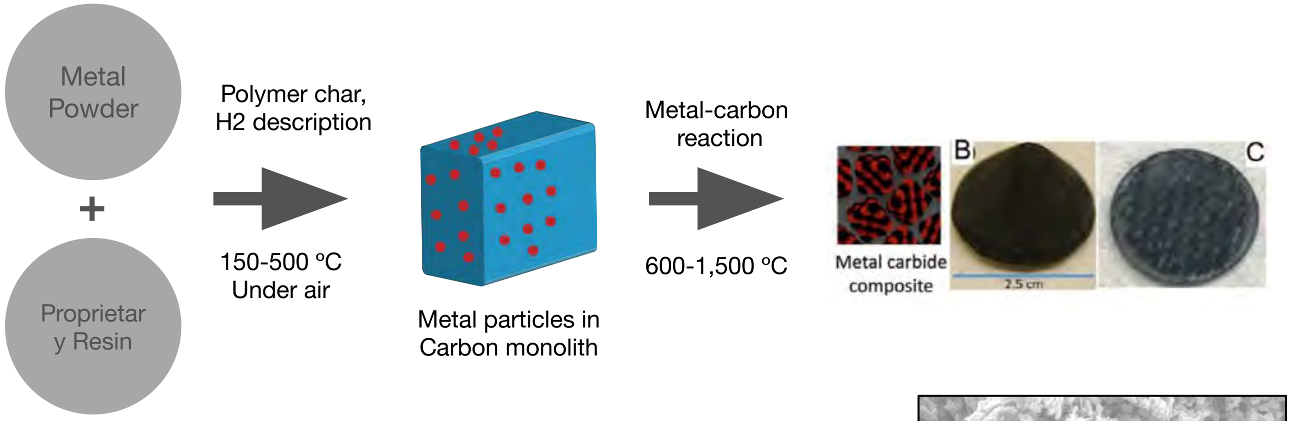
SO…

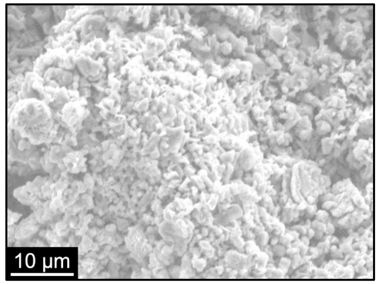
Nanoarmor can meet the most stringent of performance requirements without these burdens in long lead times and cost

Improved Material Properties

Nanoarmor has developed a platform technology to create a range of Ultra-High Temperature Ceramic Matrix Composite (UHTCMC) with exceptional physical and thermal properties and more moderate processing requirements

- TiC, B_4C, SiC, TaC, and ZrC polymer-derived ceramics with greater than 3000˚C melting points
- Excellent thermal and oxidative stability
- Excellent ablation resistance
- High thermal dissipation and thermal shock resistance
- Higher mechanical toughness than traditional carbide ceramics
- Near net-shape pre-sintering, low shrinkage (<5%) post-sintering
- Fibers, fillers, and nanostructures are easily dispersed for additional customization and reinforcement
- Achieved near theoretical densities (>95%) in single-step process (no reinfiltration or densification required)
- Sintering can be performed at ambient pressure and low temperature (<1450˚C)
- Can produce graded structures to aid in adhesion to vehicle underbody as a thermal protection coating





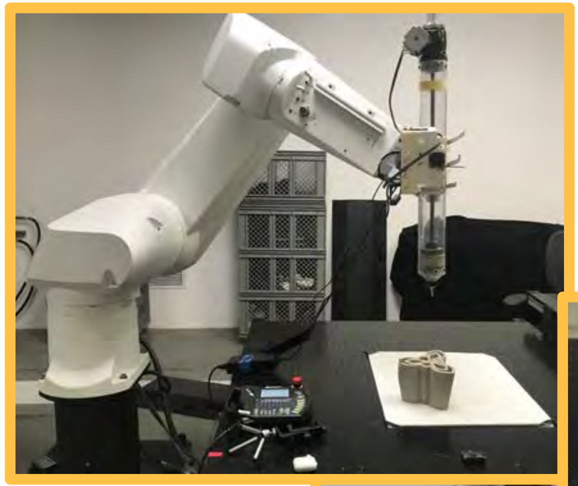
Synthesis process for Nanoarmor UHTCMCs (above) and the resulting homogenous microstructure (right) without any additional densification steps

“The [Nanoarmor] ceramics are nanocrystalline, chemically pure, dense, lightweight, mechanically tough, and exhibit excellent stability in high-temperature oxidative and ablative environments.”
– US Naval Research Laboratory

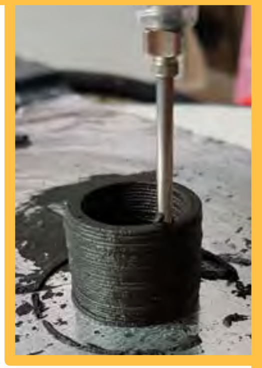
Additive Manufacturing Capabilities

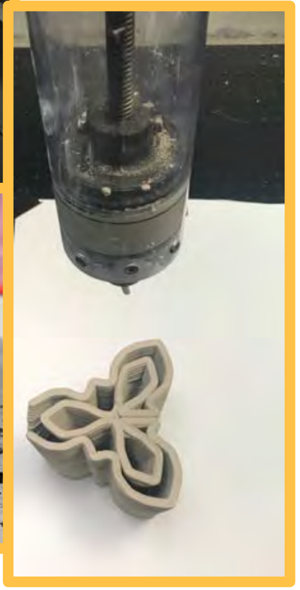
Nanoarmor UHTCMCs have been successfully processed using additive manufacturing (3D printing) technologies

- Additive manufacturing (AM) technologies enable rapid prototyping, automated manufacturing, and complex part geometries that have been previously not possible for high temperature materials
- Nanoarmor ZrC has been successfully extruded into near-net shape parts using an extrusion-based AM method
- Nanoarmor has also developed accompanying software controls to aid in the manufacture of complex geometries and to enable application of the material as a protection coating to complex bulk structures
- Nanoarmor printed parts still maintain near theoretical density after sintering without requiring multiple densification steps
- Current work is being done to expand to other AM processes including powder bed methods, gel casting, and free-form injection molding



Nanoarmor ZrC has been successfully extruded into complex near-net shape parts via additive manufacturing processes





Current Traction

Nanoarmor maintains a close research partnership with the Advanced Materials Section at the US Naval Research Laboratory (NRL) and holds exclusive license to several of their high-temperature material technologies as part of their IP portfolio.

In June 2020, Nanoarmor successfully completed Phase I of an SBIR contract award with the Missile Defense Agency (MDA) to further develop their high temperature material technologies for implementation into MDA's missile defense strategy for hypersonic vehicle threats. A Phase II proposal has been submitted and is expected to be awarded.

Nanoarmor has received letters of support and/or expressions of interest from five different research and development teams at three of the major prime Department of Defense contractors, an important first step in moving towards a full material acquisition program.

The recent launch of Nanoarmor's "Early Adopter" program is establishing and strengthening customer and supply chain relationships while providing a cost-effective avenue for collaborative R&D projects.

Nanoarmor Core Team

Terrisa Duenas, PhD
CEO

- 20 years commercializing nanotechnologies
- Department of Defense Nanotech SME
- Fortune 200 Division Chief Scientist
- PhD, Mechanical Engineering / Smart Material Composites, UCLA

Jack Roe
Business Development

- 4 years technology commercialization
- 5 years president of oil & gas services company
- 9 years Department of Defense contracting in Iraq
- BS Computer Science, Boston College
- MA, International Relations, A&S UPenn
- MBA, Finance, Wharton UPenn

Brett Cornick
Materials & Simulation Lead

- 2+ years experience developing material models and software tools
- 4+ years technology start-up experience
- Young Professionals Chair, AIAA
- BS, Chemical Engineering, Nanotechnology Emphasis, USC
- MS, Materials Science, Modeling and Computation Emphasis, UCLA

Next Steps

1. In person meetings with Nanoarmor technical engineers to conduct deep dive discussions regarding the advancements Nanoarmor materials could make in current and future technologies.
2. In person meetings between Nanoarmor and investor finance teams to understand investment budget and ROI.
3. Addition into Nanoarmor's supply chain and customer landscape to keep up to date on further research developments and results of the Phase II Missile Defense Agency SBIR award contract.
4. Secure investment to establish manufacturing capabilities utilizing the licensed NRL patents covering new, scalable methods to manufacture novel Ultra-High Temperature Ceramic Matrix Composites.

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