Ultra-lightweight, thin, tunable and broadband flocked Carbon Fiber composite Radar Absorbing Materials (RAM)

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1. Abstract

TangiTek has developed a novel class of patent-pending, nonwoven, magnetically loaded, flocked carbon fiber composite radar absorbing material (MF-RAM).[5-6] This technology is at DoD TRL 3. MF-RAM is formulated as an ultra-lightweight, thin, tunable and broadband RAM in the X and Ku bands.

We propose to develop advanced lightweight MF-RAM material that can be integrated into soldier equipment systems and clothing. MF-RAM will provide effective soldier signature management against radar threats improving soldier protection and stealth. This improves soldier lethality and provides decisive battlefield edge.

2. Technical Background

Electromagnetic interference (EMI) shielding materials are either absorbers or reflectors (*Figure 1, left*).[1-3] Microwave absorbers are used in EMI mitigation in antennas, cables, enclosures, chipsets and electronic components to meet Federal Communications Commission (FCC) regulations and standards. Microwave absorbers include RAM which are used for signature and radar cross section (RCS) reduction for stealth operations of DoD assets such as aircraft, unmanned aerial vehicles (UAVs), submarines, ships, tanks and soldier equipment, etc.[4]

Conventional absorbers are generally either magnetic or dielectric types. Magnetic absorbers are thin and offer broadband absorption. The main disadvantages of magnetic absorbers are excessive weight and cost. Dielectric absorbers generally have no magnetic properties. They are usually made using low cost, lightweight foams and elastomers, are narrowband, and are extremely thick. The main disadvantages of dielectric absorbers are their narrowband response and thickness. Currently there are no cost-effective, broadband, lightweight and thin absorber options.

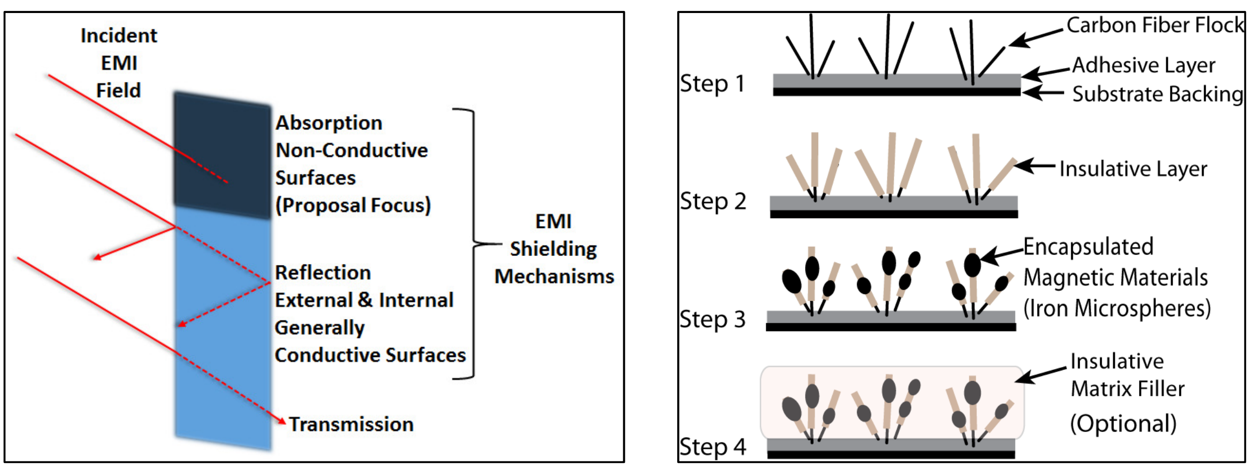

Figure 1. (Left) General EMI shielding mechanisms. Our focus is microwave absorbing material. (Right) Basic fabrication steps for TangiTek MF-RAM test samples. Bench scale production can be scaled using equipment from materials coating and automotive industry.

3. Innovation

TangiTek has developed MF-RAM - a magnetically loaded, flocked carbon fiber (CF) composite RAM. Flocking is a process of electrostatically depositing many small fiber particles (called flock) onto an adhesive coated surface or substrate. We use commercially available, chopped polyacrylonitrile (PAN) based CF as flock (≈ 1 to 3 mm), dielectric materials and magnetic materials (3 to 10 μm). The CF is flocked in the vertical "z-plane", relative to the substrate in the horizontal "x-y plane".

Figure 1 (right), illustrates the basic steps used to construct MF-RAM samples for laboratory and bench scale testing at TangiTek. The vertical flocked CF structures are preserved by spray coating with an insulating material. The individual CF are insulated from each other, resulting in a nonconductive top surface (horizontal "x-y plane"), required for high performance absorbers. Magnetic particles (zero-valent iron microspheres) are electrostatically deposited onto the vertical flocked CF. Prior to application, the iron microspheres are combined with insulating materials that provide protection against wear and corrosion. Finally, we can encapsulate the absorber matrix with high-loss dielectric resin materials such as epoxy, silicone, neoprene, polyurethane, foams, aerogels, acrylic blends or other elastomers depending on application specifications. This filler material generally improves strength and durability of the absorber and protects the composite from wear, corrosion and oxidation. The density of CF flock, loading of magnetic materials, number of flock layers, backing materials, and matrix composition can be varied for frequency response and application requirements. Both regular and irregular shaped objects and substrates such as woven or non-woven textiles, paper, PVC, sponge, metals, alloys, ballistic fibers (Kevlar, Twaron), CF structural elements and plastics can be directly flocked with MF-RAM to absorb incident microwave energy. The random orientation of the microscale CF flock (*Figure 2, top middle*) mimics the pyramidal surface geometry of typical absorbers seen in anechoic test chambers. The surface presents a diffusive plane for incident EM energy. The flocked CF, high-loss dielectrics and matrix filler absorb higher frequency EM energy, while the magnetic loading absorbs lower frequency EM energy, yielding a broadband absorber.

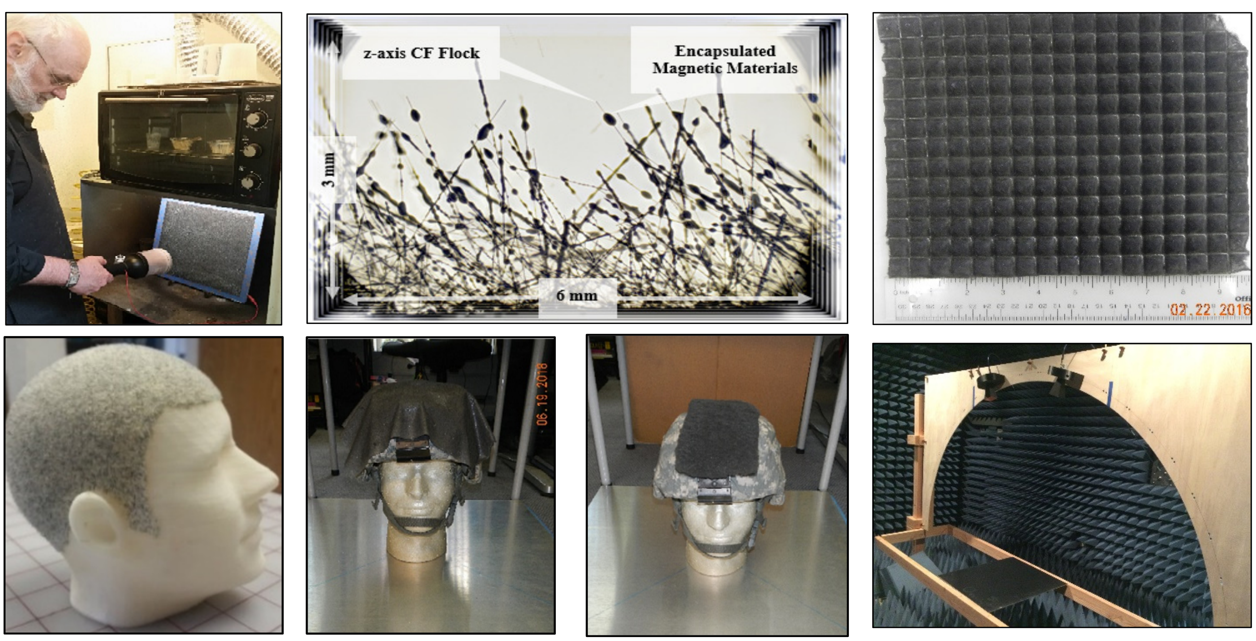

Figure 2. (Top, Left) MF-RAM sample preparation at TangiTek, CF flocked onto an adhesive surface; (Top, Middle) 20X magnified stacked focused images showing side view of MF-RAM microstructures on a paper substrate; (Top, Right) MF-RAM flocked onto a ridged pyramidal epoxy substrate; (Bottom, Left) MF-RAM flocked directly onto a 3D printed head. MF-RAM can be flocked directly onto surfaces like soldier body armor and helmets; (Bottom, Middle) existing nonwoven MF-RAM samples applied to exterior of an Army Combat Helmet (ACH) - initial pre-feasibility tests suggest this material can be developed as an interior or exterior helmet liner; (Bottom Right) NRL Arch reflectivity testing of MF-RAM in Ku band, in PSU anechoic chamber.

Figure 2 (bottom middle two images) show existing MF-RAM samples applied to Army Combat Helmet (ACH) to reduce radar reflections. Preliminary, in-office testing of MF-RAM samples overlaid on an ACH exhibits strong absorption (10-24 dB) in the X and Ku bands (*Figure **3***).

These illustrations of MF-RAM application to an ACH represent pre-feasibility concepts and do not show product integration. With Army support, such concepts can be refined and rapidly developed into test samples for incorporation into soldier protection systems such as body armor (Modular Tactical Vest, Interceptor Body Armor), helmets (Advanced Combat Helmet, Enhanced Combat Helmet) and uniform textiles.

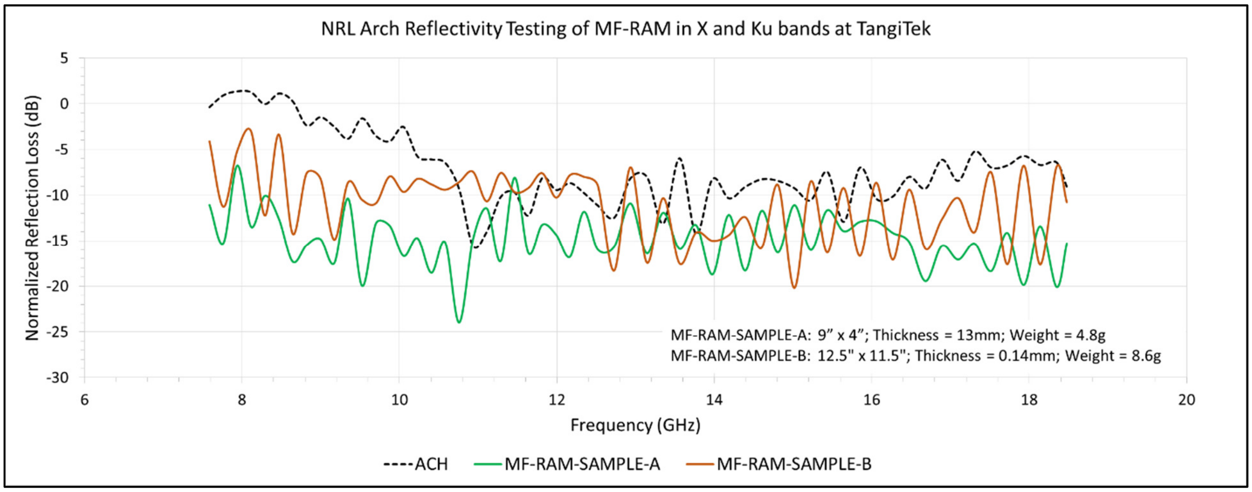

Figure 3. An ACH with covering was used for characterizing baseline reflectivity. MF-RAM samples were overlaid on the helmet (shown in Figure 2) to measure reflection loss in the X and Ku bands.

Testing of MF-RAM samples in comparison to commercially available magnetic-RAM (MAGRAM) allows us to establish Key Performance Indicators (KPIs) that can be met or exceeded for various applications (*Table 1*).

Table 1. KPI comparison of MF-RAM test sample versus a commercially available product.

Absorber Description	**Weight/Area (gm/inch^2)**	**Thickness (mm)**	**Avg. Absorption In 6 – 12.5 GHz (dB)**
MR11-0041-01 MAGRAM	2.23	1.12	-4
Ultralight MF-RAM	0.32	0.60	-10
KPI Improvement	**86% Weight Reduction**	**46% Thickness Reduction**	**-6 dB 4X Attenuation**

4. Application to Army's Modernization Priorities

Recent advances in enemy electronic warfare, battlefield and ground surveillance radar and detection capabilities pose direct threats to US infantry forces. To counter these threats, RAM with proper thickness, cost, efficiency, weight, hardness/flexibility, stability, EM and physical compatibility are needed. EM features on various substrates and fibrous materials play an important role in the ability to camouflage asset movements. Stealth movement of warfighter on the battlefield is a key priority for the military. [8,9] The incorporation of advanced lightweight MF-RAM material into soldier equipment systems and clothing will improve soldier lethality by providing improved soldier protection and stealth.

MF-RAM can be incorporated into next-generation RADAR systems for antenna isolation, beam forming applications. Advanced ultra-lightweight, ultra-thin MF-RAM for RCS reduction for the next generation of combat vehicles and aircraft in hostile environments can increase survivability of the platform and mission success by defeating the threat of radar detection.

5. Related Work

5.1. NSF

In July 2017 TangiTek received an NSF SBIR Phase I Award #1721863 titled "Novel Three Dimensional Flocked Carbon Fiber Microwave Absorbers". Ongoing research provides the feasibility, foundation and technical data (fundamental frequency dependent EM parameters such as permittivity – ε, permeability - μ) of MF-RAM test samples need for future product development.

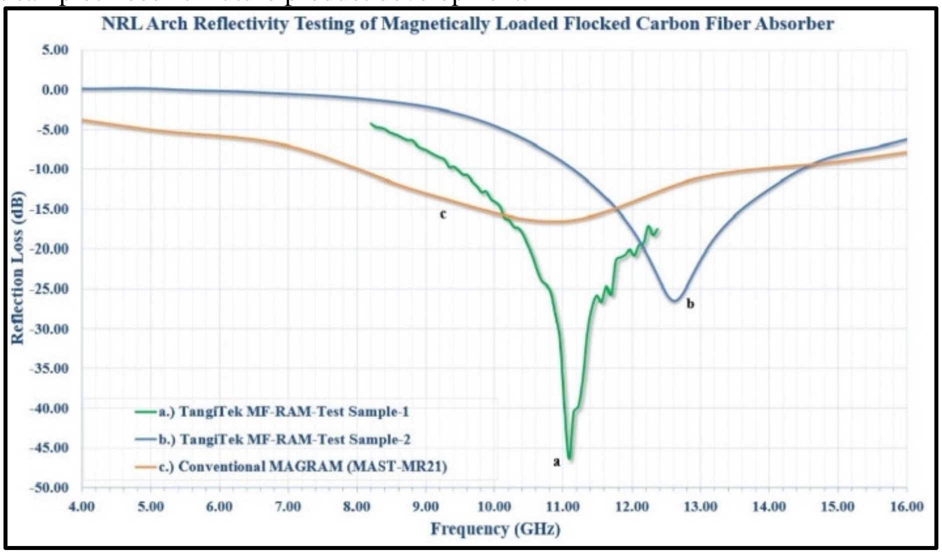

Figure 4. NRL Arch measurement of reflection losses of MF-RAM test samples and commercial MAGRAM (MR21). MF-RAM samples weigh ≈ 0.32 g/in^2 in comparison to MR21 which is ≈2.8g/in^2. Both MF-RAM samples and MR21 are of comparable thickness of 1 to 2 mm. MF-RAM exhibits broadband attenuation of -5 dB to -10 dB at the edges of X-band. MF-RAM Test Sample-1 has an attenuation peak of ≈ -46 dB at 11.1 GHz, while Sample-2 has a peak attenuation of ≈ -27 dB at 12.6 GHz. Data indicates MF-RAM shows strong absorption across X and Ku bands. Test samples construction, testing and data analysis funded in part by the NSF SBIR Phase I award.

5.2. US Navy SSC Pacific (SPAWAR)

TangiTek supplied MF-RAM test samples to SPAWAR in February 2016. Tests conducted by Mr. Melvin Pascoguin (Ph. 619-553-6012; Email: pascogui@spawar.navy.mil) showed that the samples provided ≈3-6 dB improvement over a commercially available absorber. TangiTek and SPAWAR are in the process of negotiating a CRADA.

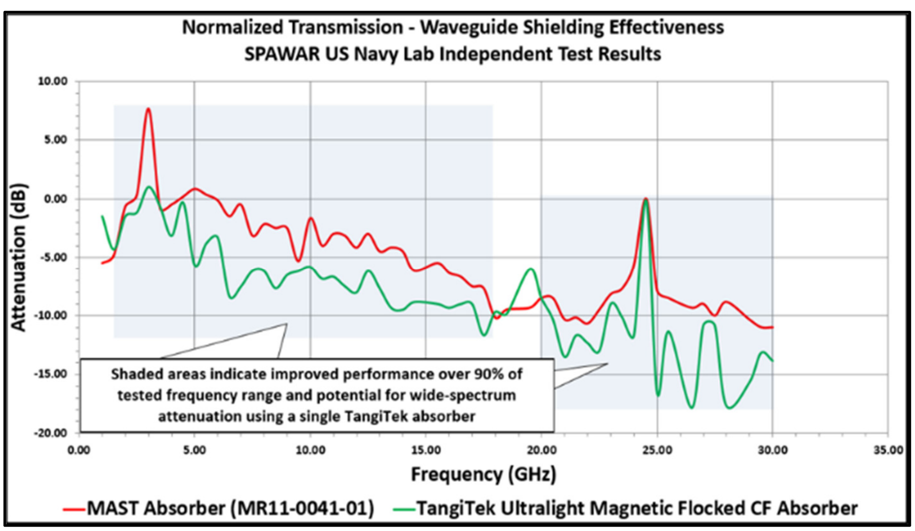

Figure 5. Waveguide measurement of attenuation performance of MF-RAM samples in X and Ku bands (SPAWAR).

5.3. Portland State University

TangiTek has developed a strong collaborative and ongoing relationship with PSU to develop RAM test, measurement and modeling capacity. Dr. Pejčinović (Ph. 503-725-5416; Email: pejcinb@pdx.edu) is our primary contact.

6. References:

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