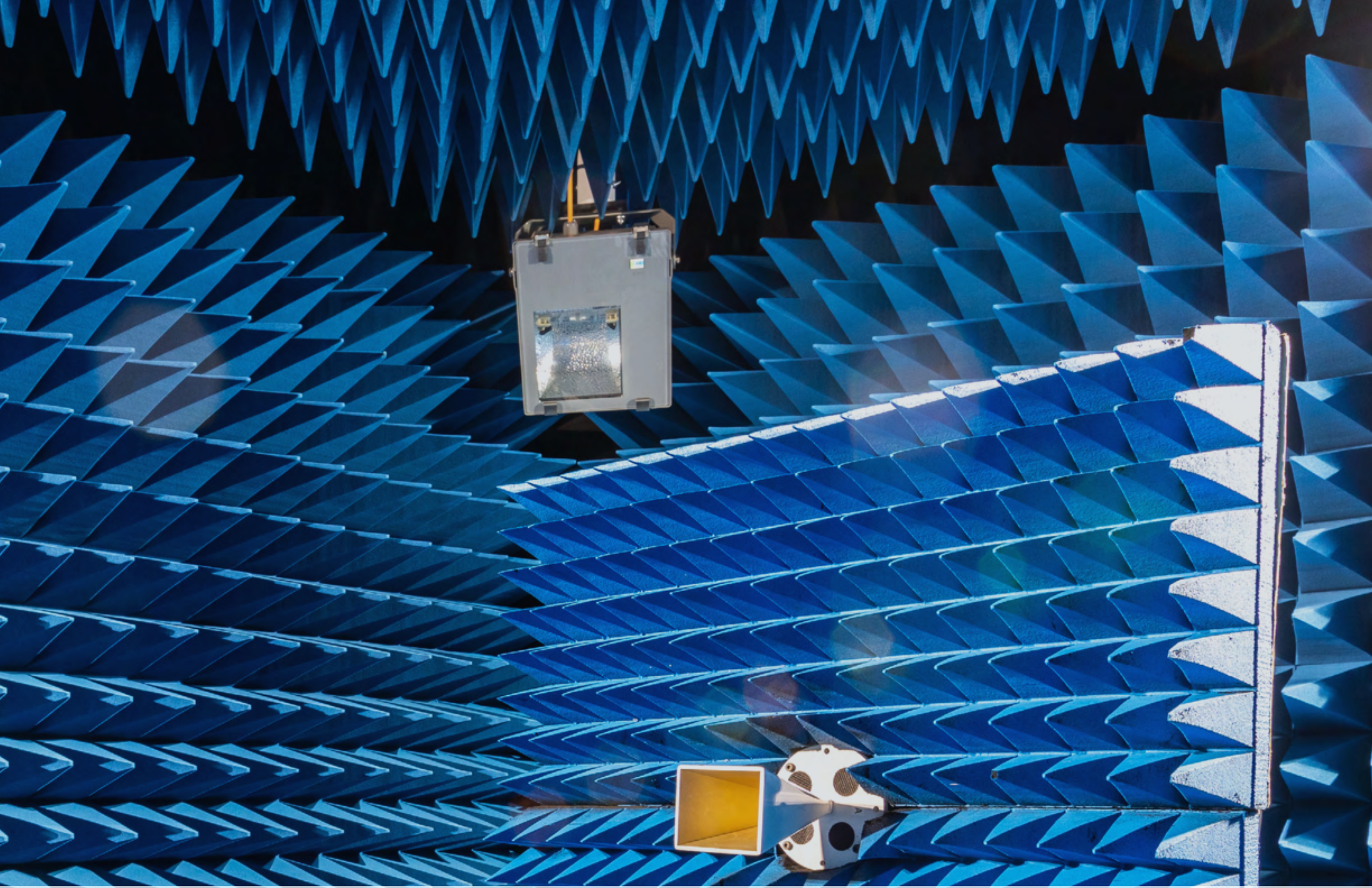


Clearly Superior: Transparent RFI/EMI Shielding Outperforming Copper Foil

How a new category of advanced shielding material transparently offers superior protection even for touchscreens, windows, buttons, or other openings in electronic devices.

CHASM™

Table of Contents

Clearly Superior: Transparent RFI/EMI Shielding Outperforming Copper Foil

Introduction

01

With accelerated penetration of sophisticated electronics into nearly all devices we use on a daily basis – some providing life-saving safety operations – protection of EMI/RFI exposure from these devices or interference to these devices is critical for safe and continued operation. As an example, the automotive electronics cost as a percentage of total car cost has exploded from a mere 5% in 1970 forecasted to more than 50% by 2030 some providing real-time safety monitoring. Keeping Advanced Driver Assistance Systems (ADAS) active not only protects the life of the driver, but also all the drivers of the surrounding vehicles on the road. Compounding the complexity, consumers preferred to interact with electronic devices through touch screens which create readymade apertures for EMI/RFI radiation exposure.

However effective, traditional “faraday cage” or opaque copper or metal shields can no longer satisfy the design and esthetic goals for modern electronic systems. Whether for clean sheet designs of next generation products or retrofitting existing product solutions, an easy to deploy transparent shielding film enables product designers to apply EMI shielding solutions quickly and at manufacturing scale. Tuned to desired frequencies using a new category of advanced materials known as nanotube hybrids, EMI shielding solutions can be fabricated for maximum impact and deployed with "peel & stick" ease both with and without ground planes.

In today's era of smartphones, wireless networks, and IoT products, humans are surrounded by radio frequency (RF) energy over a broad range. Electronics designers and PCB layout engineers have always needed to account for RF emissions from their products in order to remain compliant with EMC regulations, but the challenges involved have increased over time as more devices regularly create spurious emissions at RF frequencies. This is in addition to EMI generated at lower frequencies, such as from switching regulators, noisy crystals, displays, or power bus ripple. All of these factors are exacerbated further as more devices run at fast edge rates in smaller packages, and today it's common to see small MCU-driven electronics have the similar EMI and power integrity problems as high-speed digital systems.

Given the regulatory requirements on EMC for electronic assemblies, designers may need to add shielding to a device, either on the board, on the enclosure, or both. Shielding has always been challenging to implement on a PCB and in a housing after an EMI problem has been discovered as it is almost never considered in the initial design. In the event PCB layout changes do not solve EMI problems, designers may resort to adding an elastomeric shielding compound to mating surfaces, surface-mount shielding can to the PCB, metal plating to the enclosure walls, or all of the above. These are then tied back to the system ground to eliminate any floating metal in the system and ensure high shielding effectiveness (SE).

While these measures generally work and will help suppress radiated emissions, they add cost, size, and weight to a design, and their implementation can drive extensive redesigns of a new product, delaying production schedules and time to market. In addition, none of the above measures can be implemented on a transparent window, display, or lighting element. These measures would also be difficult to properly implement in a foldable device, such as newer folding smartphone screens. RF emissions from displays and touchscreens are emitted from the exterior side, so a transparent shielding material is placed over the device as an absorber. Some materials have been developed to address this demand for shielding but it is often difficult to reconcile VLT, SE, film thickness, and flexibility simultaneously.

Today, advances in new transparent conductive materials are directly addressing these shielding challenges, as well as other applications like transparent heating and transparent printed antennas. Carbon nanotube (CNT) materials are an ideal material platform in these applications thanks to their printability on transparent substrates, high VLT, and high absorption at radio frequencies. To see how this new class of materials is addressing challenges in transparent RF shielding, this whitepaper will outline how CNT-based thin film materials can be incorporated into original equipment or added as an aftermarket product, as well as how these materials compare to metallic shielding films. A comparison of form factor, implementation, and capabilities shows that transparent materials can out-compete traditional shielding solutions in multiple market segments.

Transparent Conductors as RFI Shielding Materials

The use of transparent conductive materials as electromagnetic shielding in electronics is not new, but their application in some products has been limited by several factors. Many high-end products in several industries require shielding on the exterior side of touchscreens, displays, and windows to ensure EMC compliance, leaving a transparent shielding material as the only option. Examples include equipment for electronics testing and measurement, medical equipment, and military electronics. Transparent RFI shielding can be incorporated into touchscreens, windows, and displays in two ways:

1. Directly incorporated in a substrate or window material during manufacturing
2. Applied to a display or window as an add-on material during or after assembly

The current range of candidate materials for use as RFI shielding include conductive metal oxides, metal meshes, nanowires, and carbon-based materials. Some solutions are more easily incorporated into the manufacturing process, while other solutions are best applied as an add-on material.

02

Conductive Oxides and Metal Mesh Films

Today, the simplest touchscreen electrode matrices are built from transparent conducting films (TCFs) made from conductive doped metal oxides like FTO, AZO, or ITO. These materials provide anywhere from 1 to 100 OPS sheet resistance, depending on the film thickness and dopant content. An alternative TCF with similar somewhat lower sheet resistance values is porous metal mesh films. These materials are used as touchscreen electrodes, as well as a shielding material for windows and displays. Substrates for these devices include glass or a flexible polymer (polycarbonate, PET, or PMMA), requiring the metal film to be carefully incorporated into the manufacturing process or added to the exterior of the screen or window during assembly.

TCFs made from conducting oxides have been successfully used as electrodes for touch screens and a variety of novel optoelectronic devices, and they dominated the touch screen market as an electrode material until recently. As a conductive material, TCFs can provide some natural shielding along the surface of the screen, but this is clearly insufficient given the known EMC challenges. While a TCF add-on film could be placed to provide some shielding, engineering a metal oxide TCF with low sheet resistance and cost without sacrificing transparency remains a challenge. While thicker metal oxide TCFs have higher conductivity and lower sheet resistance, they have lower VLT, which defeats their purpose as a highly transparent conductor in the visible range.

Flexible Shielding Materials

The advent of foldable consumer electronics has encouraged production of flexible display materials and shielding materials that can be added to existing displays or incorporated into displays during manufacturing. New touch displays are being made from active-matrix organic LEDs (AMOLEDs) that can be folded and flexed; these materials are currently used in foldable smartphones, but they could also make their way into flexible wearables. The SE of these materials used as electrode matrices is lower than that of oxide TCFs, so some additional shielding material is still needed. Because conductive metal oxides like ITO are brittle materials, they should not be used on a polymer substrate as an add-on shielding material.

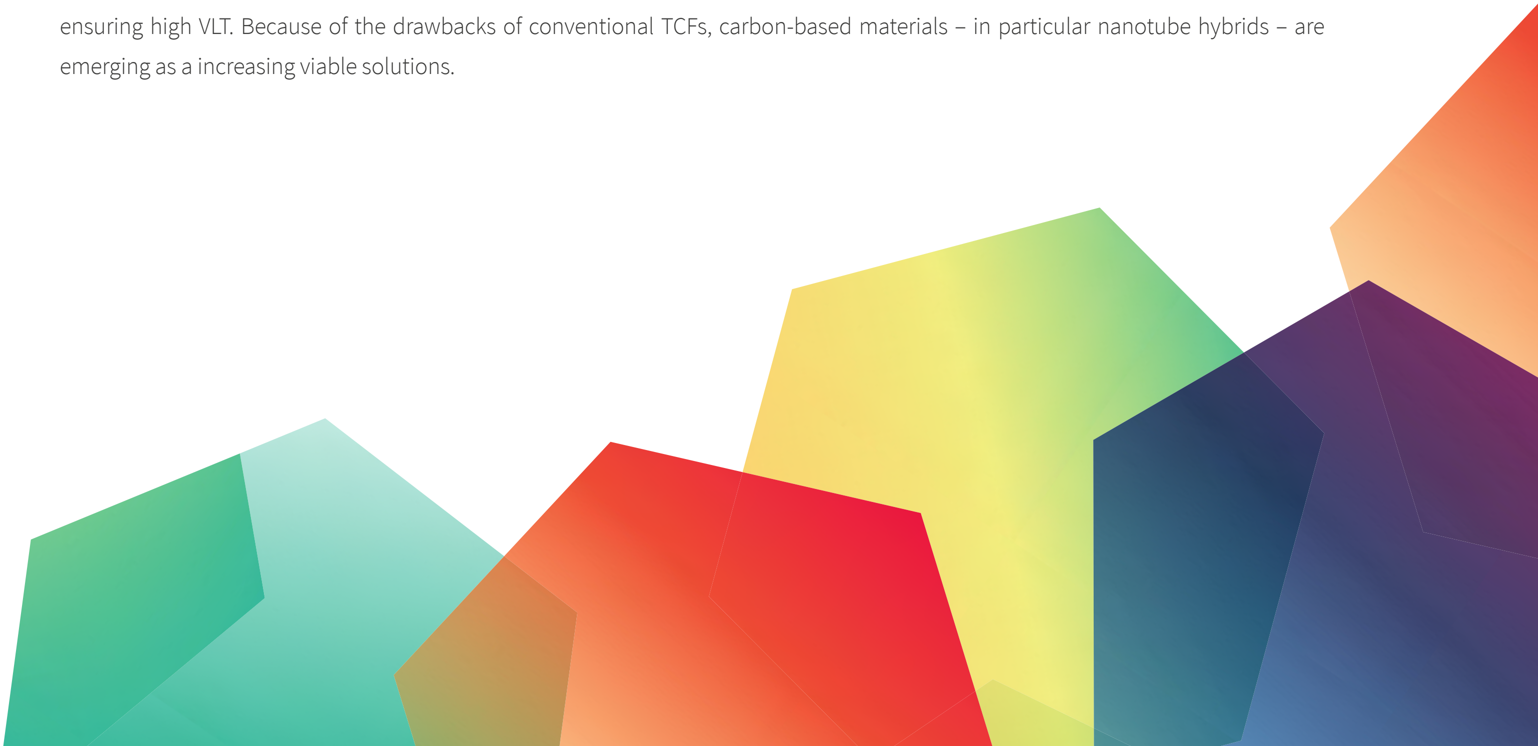
The drawbacks of metal oxide TCFs as shielding materials has motivated development of metal porous mesh materials, which have lower sheet resistance than oxide TCFs. These materials are advantageous as they can be deposited on flexible transparent substrates and used in foldable electronics. This type of flexible RFI shielding material is commercially available as an add-on that can be applied directly to windows or displays by cutting it from a roll of material and applying it to a display with an adhesive or by stretching across the display/window. However, commercially available material can only provide a sufficiently high SE value if the film is made sufficiently dense, which brings the VLT value below 70%.

Other unique thin-film metallic materials have also been reported in the literature or are available commercially. These include Ag nanowire (AgNW) materials, which provide among the lowest sheet resistance values for thick films (<1 OPS), but they tend to have less than 90% VLT, are expensive, and can tarnish if not hermetically sealed. While foldable hybrid metal/metal-oxide TCFs have been reported in the literature, these films only provide maximum VLT up to 80% and SE reaching ~30 dB, which do not meet the operational requirements of transparent RFI shielding materials.

The table below summarizes the characteristics of various transparent RFI shielding materials used in windows and displays. Typical SE values are shown at ~1 GHz.

Shielding Material	SE (dB)	VLT	Flexible?
Metal Oxide Marix	Up to ~30 dB	Up to 80%	No
Metal Mesh	Up to ~100 dB	Up to 70%	Yes
Hybrid Metal / Metal Oxide	Up to ~30 dB	Up to 80%	Yes
Metal Nanowire Films	Up to ~40 dB	50% to 90%	Yes

Typical shielding and VLT requirements in transparent flexible electronics require at least 40 dB SE and ~90% VLT, and it is difficult for the current class of commercially available materials to meet all requirements. A best-in-class alternative shielding material should provide near this level of broadband SE (from ~100 kHz up to at least ~10 GHz) to suppress RFI from multiple sources while also ensuring high VLT. Because of the drawbacks of conventional TCFs, carbon-based materials – in particular nanotube hybrids – are emerging as a increasing viable solutions.



Hybrid Nanotube-Based Transparent RFI Shielding Alternatives

More recently, researchers have looked to alternative advanced materials such as nanotubes and graphene as a material platform for transparent thin-film shielding with high SE for suppressing broadband RF emissions.

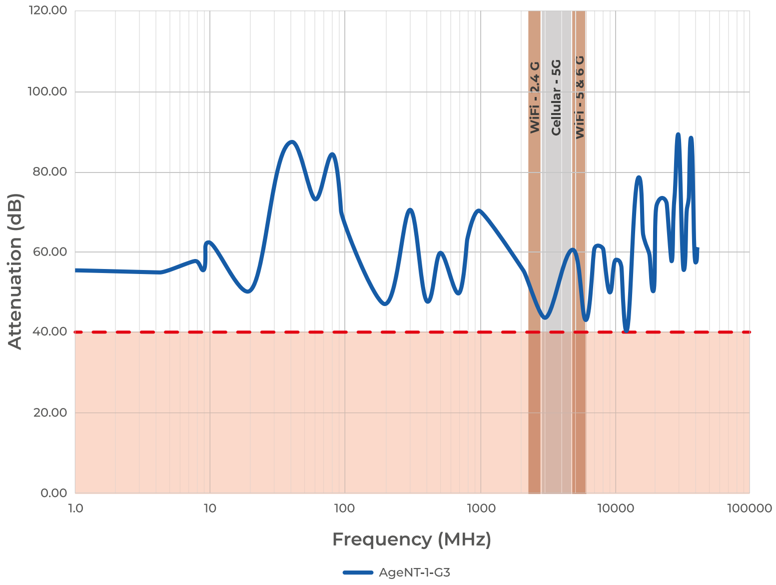
03

As aggregated, solution-processable materials, both can be deposited on a flexible substrate and folded or formed without fracturing, and the material properties can be modulated based on the nanotube morphology or graphene flake size. Between these two carbon materials, nanotubes represent a more promising platform as they are less expensive to produce at scale, and select suppliers can use sophisticated methods to modulate the size and structure of these materials during synthesis.

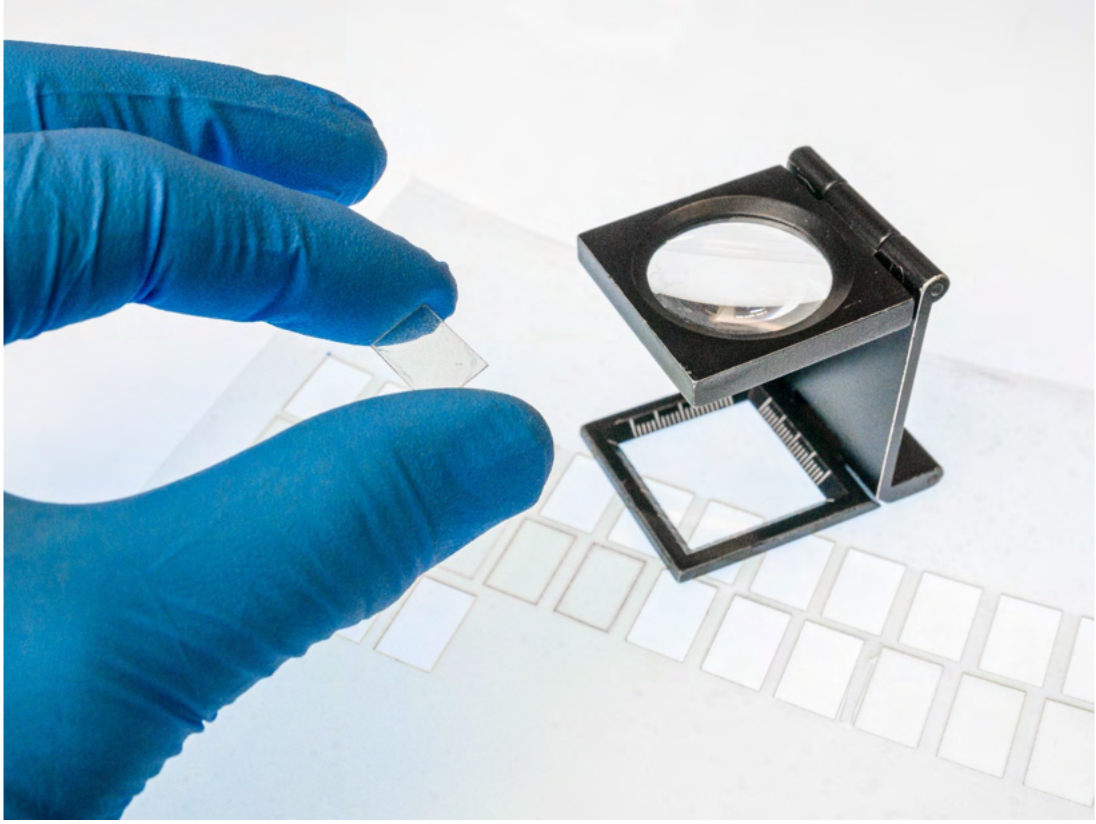
Nanotube-Metal Mesh Hybrid Films

Nanotubes can be hybridized with metal mesh (MM) films and when deposited onto flexible substrates. This type of Nanotube-MM hybrid on a thin plastic substrate is highly adaptable and can be formed over an assembled touchscreen, display, or transparent window without impacting functionality. The VLT value of these materials ranges from the mid-80% to mid-90% while providing high shielding effectiveness over a broad bandwidth. An example SE measurement for a Nanotube-MM film on PET is shown below. As can be seen in the figure, the peak attenuation exceeds 90 dB and remains above 40 dB across the entire measured from 100 kHz to 10 GHz. This addresses a range of possible EMI sources, spanning from clocks to switching regulator noise, cellular frequencies from 1G to 5G including millimeter wave, and RFI generated from power bus ripple, all of which are common sources of RF emissions in systems with touchscreens.

Shielding effectiveness of a Nanotube Hybrid MM film printed on a PET substrate.



Requirements for cellular and WIFI connectivity of contemporary devices in consumer electronics and industrial applications are commonplace. Engineers and designers looking to safeguard across the expected operational frequencies ranges generally set an objective of achieving 40dB of shielding effectiveness in the range of 100kHz to 40GHz. As shown in the figure above, the MM nanotube hybrid of AgeNT-1-G3, consistently delivers shielding effectiveness equal or well above the 40dB desired value across the entirety of the tested frequencies. Including this thin, transparent shield universally provides shielding protection – particularly across the predominant WiFi and cellular frequencies including 2G and 5G.

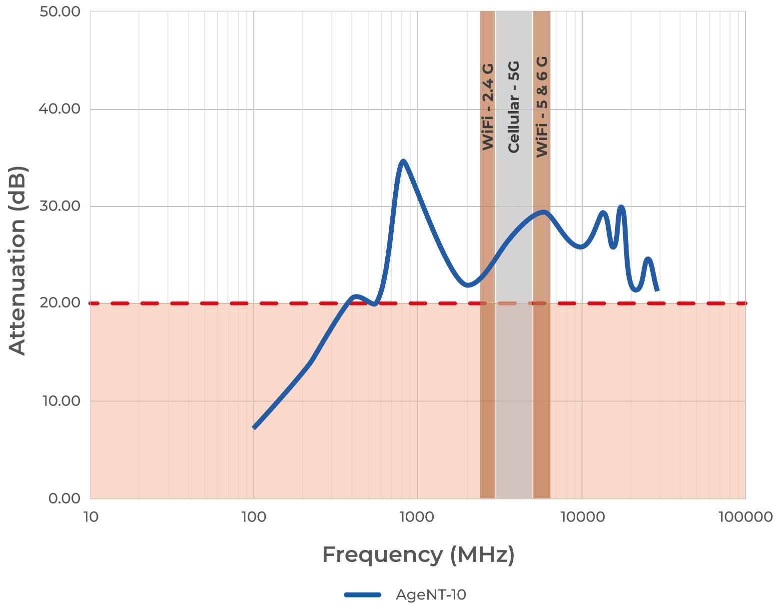


Applying an optically clear adhesive, nanotube hybrid shielding films can be selectively applied with "peel & stick" ease. And measuring under 10-mils in thickness, nanotube hybrid shielding films require little space even in existing applications having minimal clearance envelope so can be added inside existing housings or enclosures without redesign.

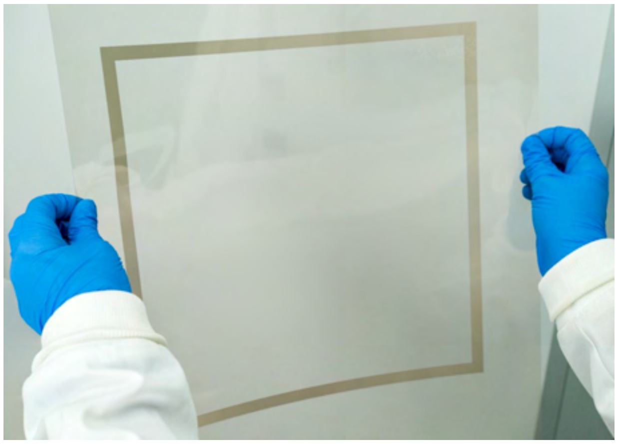
Nanotube-AgNW Hybrid Films

Another commercially available formulation for nanotube hybrid shielding films utilizes a transparent conductive substrate comprised of silver nanowire (AgNW) encapsulated with a functionalized nanotube coating. Being environmentally stable, the nanotube coating not only protects the AgNW network from moisture, humidity, and abrasion, but also creates a nanoscale conductive shield network. Effectively a nanoscale faraday cage, higher frequency waves are suppressed. Highly transparent and easily patterned to any shape, the AgNW nanotube hybrid is an ideal candidate for applications where shielding of LCD screens, user interface buttons, enclosure windows, lighted status indicators, or operational status monitors is required while not negatively impacting their individual visibility.

Common cellular frequencies shielded by thin and transparent AgNW Nanotube Hybrid films



While not delivering as universal protection as demonstrated by the MM nanotube hybrid, the AgNW nanotube hybrid can still deliver effective protection in select applications. Providing effective shielding above 20dB particularly across the predominant WiFi and cellular frequencies including 2G and 5G as shown in the figure above, AgeNT-10 provides ample protection for smartphones, tablets, or any electronic device using standard wireless connectivity signals.



The final advantage of a printed material or a hybrid film on metal mesh is the elimination of any required electrical contacts for grounding. Although these films could be grounded by directly printing a conductive busbar as previously mentioned, such as along the edge of the electrode matrix on a display, this is not required in order to provide the rated SE value. Nanotube hybrid shielding films could be left un-grounded, enabling them to be printed on a variety of surfaces without building in an electrical connection

Flexibility, Economy, and Agility of Fabrication

Traditionally fabricated from metal sheets formed to fit the intended enclosure, plated steel, copper and silver alloys, and aluminum have been staple materials for EMI shielding. Designing these shield enclosures must take into consideration necessary clearance envelopes to avoid interference with other components inside the device enclosure. Conductive plastics in tape, film, or foil form have also emerged as effective for anti-static applications, but have not reached widespread adoption with respect to shielding RF frequencies. While fabrication methods for metal sheets are mature and pervasive, tooling such as brakes, presses, punches and sheers require sizable capital investments and are single purpose. Completing all the multiple requisite steps to fabricate metal shields in sequence also takes days – if not weeks – to successfully complete.

Alternatively, EMI shielding created using nanotube hybrid films can be quickly and efficiently fabricated using low-cost screen printing for patterning, offering significant savings in manufacturing costs, processing time, and reduced risk of scrap. Creating EMI shield patches or circuits from nanotube hybrids is simply print, etch, and done. For applications requiring ground plane connection, screen printing conductive silver busbars onto the film makes them integral to the shield simplifying mass production. And since nanotube hybrid shielding films utilize a thin, flexible plastic substrate, they can be flexed, folded, or formed for easy incorporation into existing enclosure with limited space and small form factors.

Conclusion

04

Metal mesh materials are seeing a new wave of innovation thanks to the incorporation of CNTs as a conductive additive. Hybrid CNT-AgNW on metal mesh materials with flexible substrates provide an adaptable material platform as an add-on shielding film for new or existing electronics assemblies. Thanks to the solution-processability of CNTs, these materials could also be deposited with an inkjet printer in a desired pattern. Both methods give engineers a simplified way to add RFI shielding materials to new or existing electronics assemblies, providing higher SE values than existing solutions without compromising on transparency.

Increasingly sophisticated and delivering mission critical operation, electronic systems are pervasive in nearly all of our day-to-day activities. From keeping us connected to each other and an increasing array of smart devices, to ensuring our safe operation of our vehicles when commuting – especially when distracted – to delivering real-time medical diagnostic information around the globe enabling doctors in one country to treat patients in another, all depending upon wireless connections of increasing density, ensuring uninterrupted operation without interference can easily be a matter of life and death. EMI shielding provides an effective mechanism to control exposure, but traditional materials and methods do not deliver the effectivity and flexibility needed for future applications. Transparent, flexible, formable, and effective at pervasive wireless RF frequencies, nanotube hybrid shielding films offer versatility at shielding applications previously considered impossible. Proven superior in protection to even copper foil, nanotube hybrid shielding films transparently protect even in touchscreen, window, button, or other aperatures in electronic devices.

About CHASM Advanced Materials

> Our customers turn **what if** into **what is**, every day.

05

CHASM Advanced Materials, Inc. is the inventor and manufacturer of nanotube hybrids – a new class of advanced material used by global manufacturers of commercial and industrial products to dramatically improve device technology, transportation, infrastructure, healthcare, and natural resources. Leading companies across multiple industries have been first to market with their future products using AgeNT™ for transparent flexible printed electronics, NTeC™ for battery, coating, or performance additives, and Signis™ for touch buttons and sensor with superior environmental stability. For more information, visit www.chasmtek.com, or follow us on Twitter, LinkedIn, Facebook, WeChat or Instagram.

Headquarters & Applications Development Center
480 Neponset Street - Bldg. 6
Canton, MA 02021
(781) 821-0443

Nanotechnology Manufacturing Plant
2501 Technology Place
Norman, OK 73071

Clearly Superior: Transparent RFI/EMI Shielding
Outperforming Copper Foil
www.chasmtek.com

CHASM™