Coating Technology Enables Effective Missile Countermeasures

Heat seeking missiles have been in use against both rotorcraft and fixed wing aircraft since the mid-1950s, and countermeasures to deceive their guidance systems have been employed for nearly as long. Typically, countermeasures operate by generating a strong infrared signature which confuses the missile tracking system. At the heart of these systems is some form of powerful infrared emitting source. Often this source requires optical coating(s) to perform wavelength filtering needed for optimum operation. However, both the mechanical configuration of the thin film filter coatings used and the operating extremes to which they are subjected present challenges for the manufacturer.

Infrared Countermeasures

Since their introduction, heat seeking missiles have been a particularly successful and deadly threat for military aircraft. In fact, a report issued in 2009 estimated that over the preceding 25 years, 90% of all US air combat losses had been caused by heat seeking missiles.

The basic operating principles of a heat seeking missile are relatively straightforward, although the actual implementation has become increasingly sophisticated as each new generation of systems seek to overcome the countermeasures developed to thwart them. Simply stated, the heat seeking missile relies on the fact that an aircraft engine is significantly hotter than anything else in the surrounding environment. Therefore, it emits a strong mid-infrared signal which allows it to be easily identified. For helicopters, in particular, the primary sources of IR emission are the engine exhaust duct, any hot engine parts which can be viewed externally (such as turbine blades), parts of the tail boom which are heated by the exhaust plume, and the exhaust plume itself.

The peak of aircraft infrared emission is typically in the 4 µm - 5 µm wavelength range, which also happens to correspond to the window of high atmospheric transmission which occurs in the 3 µm - 5 µm band. As a result, a typical IR guided surface-to-air missile can lock on to an aircraft that is over 3 miles away. Additionally, heat seeking guidance is passive. This stands in contrast to radar, which sends out a signal that must be returned (and which can therefore be detected by the target). As a result, there is no way for an aircraft to know that it is being targeted by a heat seeking missile.

The simplest and earliest IR countermeasures were flares (hot sources) which could be dropped by an aircraft. The intent is that the missile guidance system will lock on to these, rather than the aircraft engine, and thus be lead away from the real target. However, flares only burn for a short period of time, and an aircraft can only carry a limited number of them. Furthermore, the pilot must be aware of being targeted in order to deploy flares. Especially for helicopters, which often remain relatively stationary in high risk areas for extended periods, a longer duration (always on) countermeasure was required.

As a result, heat seeking missile countermeasures based on hot sources were first introduced in the 1970s. Most commonly, these rely on a block of silicon carbide material which is heated until it radiates a significant amount of infrared energy, specifically in the 4 µm – 5 µm band utilized by missile tracking systems.

The first heat seeking missiles utilized a rotating reticle in their imaging systems which would sweep over the image of the target. When the target is off-center, this reticle movement causes a pulsed signal to be produced. When the target is centered on the sensor, the signal becomes constant. This constant signal was required by these early missiles in order to indicate that the target had been acquired, and thus allow a launch.

Typically, the countermeasures for these types of trackers employ a cylindrical mechanical shutter that surrounds the hot source and modulates its output. The resultant stream of infrared pulses is approximately synchronized with the rotation speed of the reticles thus producing a spurious signal that prevents the tracking system from locking on to the target. Alternately, for a missile already in flight, the IR pulses from the countermeasure confuse the targeting system causing it to veer off course. The countermeasure system can be either placed directly on the rotorcraft structure, or, in some cases, in a towed pod. The latter is employed because sometimes the bright infrared output of the countermeasure actually works to improve the lock of the missile on the target.

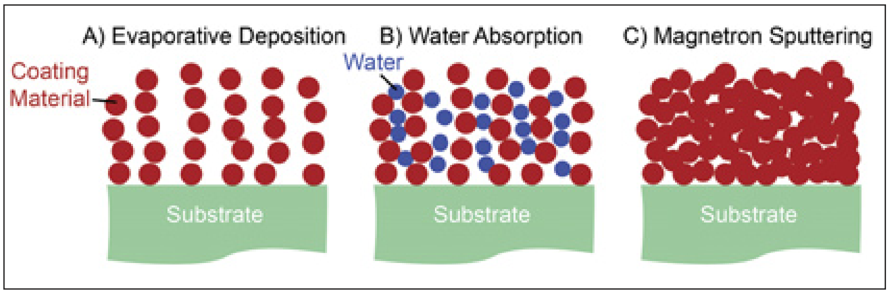

Figure 1. A) Evaporative deposition produces porous coatings which can B) absorb moisture, thus changing their spectral response. C) Sputtering produces much denser films which are largely impervious to water absorption.

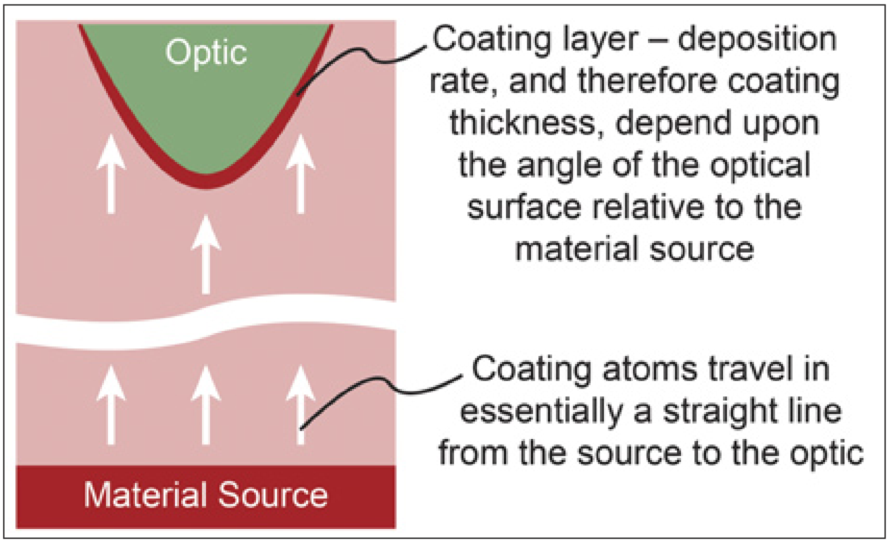

Figure 2. The long mean free path of coating material molecules in vacuum deposition techniques makes layer thickness highly dependent upon the orientation of the optical surface relative to the material source.

While subsequent generations of some missile guidance systems have moved past this simple reticle-based technique, advances in the operation of the countermeasure systems have continued to maintain their effectiveness. And, the basic concept of using a bright mid-IR source to jam or confuse the missile tracking remains unchanged.

In some countermeasure systems, the hot silicon carbide block is surrounded by a cylindrical tube, which is optically coated to modify the spectral output of the source in order to further optimize its effectiveness. The advantage of a cylindrical tube is that it makes the angle of incidence on the coating uniform (90°) in all cases. However, producing such a coating presents two significant problems. First, the coating is subjected to a very wide operating temperature range, typically around -55°C to 600°C. It must be able to survive a rapid rise in temperature (to around 400°C) when the source is first powered on. In addition, throughout this entire temperature range, the coating transmission characteristics must remain relatively constant.

The second challenge is that of uniformly coating a cylinder around its entire circumference. The specifics of both these issues, and solutions to them, are examined in the following sections.

Coating Densification for Stability

Multilayer thin film coatings selectively transmit and reflect different wavelengths based on the thickness and refractive index of the individual layers. The most widely utilized optical thin film coating technology is thermal evaporation, which

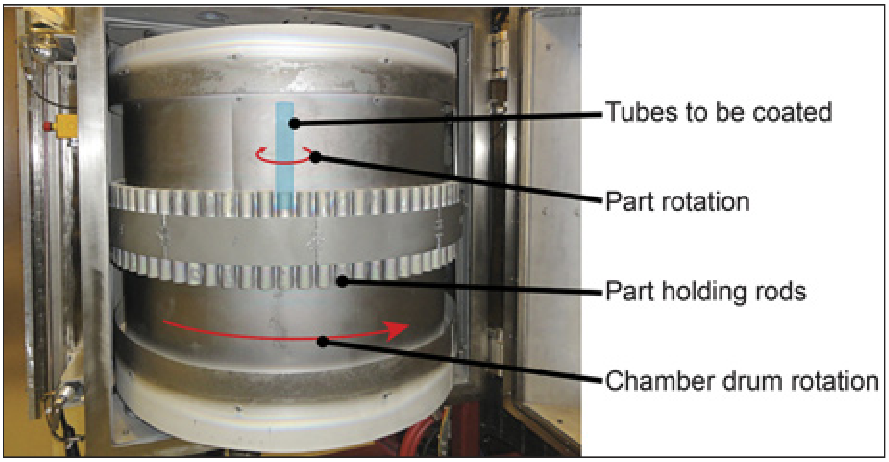

Figure 3. Specialized tooling within the DSI MicroDyn® sputtering chamber causes continuous part rotation during coating, resulting in highly uniform deposition around the entire tube circumference.

uses either resistive heating or electron beams to vaporize the source material(s). Evaporation is popular because it is compatible with a wide range of source materials, can be used to produce thin films from the deep ultraviolet through the far infrared, and is highly cost effective.

However, evaporation is a relatively low energy process. As a result, the coating material atoms or molecules don't pack in tightly in the resultant thin film, making the layers somewhat porous. This means the coating layers can subsequently absorb moisture which changes their effective refractive index, resulting in a shift in the coating's transmission or reflection properties. This problem is frequently of concern in military and aerospace applications, because the optic may be exposed to large swings in ambient temperature and humidity.

Sputtering is a coating process which increases the energy with which molecules impact the substrate surface. Consequently, the various forms of sputtering result in coatings that are substantially more densified than is possible using evaporation. This makes sputtered coatings essentially impervious to water absorption and its attendant performance shifts.

Deposition Sciences utilizes a proprietary variant of magnetron sputtering, called MicroDyn®, which is performed in a chamber under low vacuum conditions. Here, parts for coating are held on a rotating drum within the chamber and several electrically conductive (metal or semiconductor) coating targets are arranged around the circumference of the chamber. These targets are biased with a negative voltage and immersed in a magnetic field. Electrons leaving the target are contained in the vicinity due to this magnetic field. The electrons collide with the sputtering gas atoms and ionize them, and these ions are accelerated towards the target(s) because of their electrical potential. When these ions impact the target, they cause atoms or molecules to be ejected (sputtered) and deposited on to the optics. Because the sputtered target atoms are ejected with a large amount of energy, they pack densely into the thin film. Thus, this approach enables production of coatings that have both the spectral performance characteristics and the necessary environmental stability essential for countermeasures and other military applications.

Coating Highly Curved Surfaces

Another limitation of most thin film coating techniques, including both evaporation and sputtering, derives from the fact that they are performed under moderate to high vacuum conditions. This produces a relatively long mean free path for the coating material molecules, making deposition occur essentially in a line of sight to the material source. As a result, any surfaces that are "shadowed" by others from the material source, or which don't face perpendicular to the direction of material travel, don't experience deposition at the same rate (or any deposition at all) as surfaces which are perpendicular to the material travel. The resultant spatial variations in layer thickness across a part caused by this situation lead directly to unwanted variations in the wavelength characteristics of the coating.

Because of this, uniformly coating any kind of highly curved optic (domes, steep aspheres, tubes, spheres, etc.) using traditional deposition technology is challenging. Traditional coating of a shape like a cylindrical tube or full sphere also requires first coating one half of the part, and then turning the parts and performing a second coating run. This essentially doubles production costs and time.

The circular symmetry of the tubes that DSI coats for countermeasure applications provided an opportunity for the company to engineer customized tooling for the MicroDyn® sputtering system that would enable production of a uniform coating around the entire circumference of the cylinder in a single coating run. In this case, each individual tube is mounted on a rod within the coating chamber, and this tooling is configured so that the rods rotate throughout the coating process in a way that is synchronized with both chamber motion and the sputtering deposition process. The result of this motion is that every area on the outer surface of the tube is exposed to the coating material source for the same amount of time, producing uniform layer deposition around the entire tube circumference.

Conclusion

Coatings for military and aerospace applications often require performance over a very wide range of ambient conditions, necessitating fabrication methods that yield highly dense and stable thin films. Plus, the size and weight constraints of many of these applications also drive designers to use odd shaped components. Combining sputtering technology with innovative tooling concepts can meet the challenges of providing thin film coatings that meet these requirements.

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