Keynote Paper

Source Technology as the Foundation for Modern Infra-Red Counter Measures (IRCM)

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ABSTRACT

Protection of military aircraft from IR guided threats is paramount to ensure the survivability of aircrews, platforms, and to ensure mission success. At the foundation of all IRCM systems is the source; that component that provides the in-band radiant energy required for threat defeat. As such, source technology has evolved with IRCM technology to encompass the evolving systems architectures that encompass IRCM: 1) "Hot Brick" omni-directional sources; 2) arc lamps, and; 3) lasers. Lasers, as IRCM sources continue to evolve to meet the challenges of ever-evolving threats, superior techniques, economy of installation, and superior source technology. Lasers represent the single greatest advance in IRCM source technology and continue to evolve to meet ever more sophisticated threats. And have been used with great effect in all modern IRCM systems; evolving from frequency doubled CO2 lasers, to solid state lasers with OPOs, to semiconductor lasers including Quantum Cascade Lasers (QCLs); these last devices represent the latest advance in IRCM source technology offering all-band coverage, architectural simplicity, and economy of scale. While QCLs represent the latest advance in IRCM laser technology, fiber lasers show much promise in addressing multi-band operation as well as the ability to be coherently combined to achieve even greater output capability. Also, ultra-short pulse lasers are evolving to become practical for IRCM applications. Stay tuned ……

Introduction

Protection of military aircraft from IR guided threats is paramount to ensure the survivability of aircrews, platforms, and to ensure mission success. At the foundation of all IRCM systems is the source; that component that provides the in-band radiant energy required for threat defeat. As such, source technology has evolved with IRCM technology to encompass the changing and evolving systems architectures that encompass the history of IRCM: 1) "Hot Brick" omni-directional sources; 2) arc lamps, and; 3) lasers. And, as IRCM systems continue to evolve to meet the challenges of ever evolving threats, superior techniques, and economy of installation, this source technology must also evolve.

IRCM Systems can be grouped into two sub-categories, Proactive and Reactive. As such, each has its own unique source requirements. Within these IRCM sub-categories source technology must address the system mode of operation and unique platform characteristics. Typically, Hot Brick sources are heated elements which emit in the principal IRCM bands, typically un-modulated, and with the spin-by-carrier provided by a mechanical chopper assembly. These sources are typically employed in older pro-active architectures denying an adversary the ability to make lock on an intended target. Arc lamps are an extension of "Hot Brick" technology and bridge the operation between both pro-active and reactive architectures. In this capacity, they provide, depending upon architecture, that capability to defeat threats pre and post target lock.

Lasers represent probably the single greatest advance in IRCM source technology and continue to evolve to meet ever more sophisticated threats. Lasers have been used with great effect in all modern IRCM systems and have evolved from frequency doubled CO2 lasers, to solid state lasers with optical

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parametric oscillators to generate the wavebands of interest, to semiconductor lasers including optically pumped semiconductor lasers and Quantum Cascade Lasers (QCLs); these devices represent the next breakthrough in IRCM source technology offering all-band coverage, architectural simplicity, and economy of scale. Lasers are typically used in reactive IRCM system where their small beam divergence ensures rapid and effective threat defeat at standoff ranges.

While QCLs represent the latest advance in IRCM laser technology, fiber lasers show much promise in addressing multi-band operation as well as the ability to be coherently combined to achieve even greater output capability. Also, ultra-short pulse lasers are evolving to becoming practical for IRCM applications. And, as IRCM began with its foundation entrenched in pro-active architectures, modern IRCM is also evolving in this direction; ultimately denying an adversary the ability to target a platform.

1.0 The Early Days

In their earliest incarnation IRCM sources consisted of nothing more than a hot radiating source fueled by either a liquid fuel or electrical current. Typical of these were propane heaters, jet fuel powered heaters, and electrical resistance heaters. Of these, the electrical resistance heaters proved to be the more robust at defeating threats of the day. Typical systems employing these types of sources include the AN/ALQ-144 [1,2,3], Figure 1, and the AN/ALQ-147 [2,3], Figure 2.

Both systems consist of an electrical resistance heated Silicon Carbide block that radiates a large amount of infra-red energy. It is surrounded by a large cylindrical mechanical shutter that modulates the infra-red output producing a pulsing pattern that is disruptive to the IR guided threat's guidance logic. Early infrared guided missiles used a rotating reticule, when a target was not on the sensor's centerline, it would produce a pulse as the reticule swept over the target. When the target was on the sensor's centerline, the sensor would produce a constant signal. This constant signal was required by the early missiles to produce a "lock on" that would allow a launch [2].

Both the AN/ALQ-144 (rotary wing) [2,3] and AN/ALQ-147 (fixed wing) [2,3] IRCM system's used mechanical chopper assemblies to provide the spin-by-carrier optical break-lock signals. In this capacity, they could be rather clumsy having to rely upon a high current resistance heater and a mechanical chopper to modulate the output. Also, the systems required a specific warm-up-time whereby the resistance heaters had to reach a predetermined temperature before they would emit sufficient output within the missile seeker bands of interest to be effective.

Each system produced a pattern of pulses that was approximately synchronized with the rotation rate of these older seeker reticules. Before launch this would prevent the missile actually locking onto the target, preventing the operator from firing the missile. After launch this would cause the missile to think that the target was off to one side, and cause the missile to steer away from the aircraft carrying the IRCM [2,3].

Figure 1. AN/ALQ-144 IRCM System [1]

Figure 2. AN/ALQ-147 IRCM System [4]

The successor to this "Hot Brick" technology was in the form of arc lamps [2,5]. In this capacity, the lamp was modulated at a specific rate set to provide maximum confusion of the threat seeker. When high electrical current was passed through the lamp, emission was produced in the preferential IRCM seeker defeat bands. The advantage of these lamps was the fact that they could be modulated with a specific waveform rather than operated continuously and employing a mechanical shutter/chopper assembly to modulate the output. While warm-up time was less than glowers, they did require a simmer current be supplied to keep the active gas at a constant temperature. In this capacity, they provided their own signature to the platform and did not have a 100% depth of modulation, which further added to platform signature. Additionally, these systems were very heavy and current hungry being reserved for the largest of platforms. A depiction of the AN/ALQ-157 is shown in Figure 2 with the source shown in Figure 3.

Figure 2. AN/ALQ-157 IRCM system [5]

Figure 3. AN/ALQ-157 IRCM System Cs Arc Lamp [5]

2.0 A Bit Later in IRCM History

In the late eighty's an interesting source technology emerged in the form of a Surface Discharge [6,7]. This spectrally enhanced plasma was formed by discharging an electrical current across the surface of a material that had atomic transitions within the specific wavebands of interest. By carefully selecting the material, all IRCM Band operation was possible. Figure 4 depicts the basic principal of operation of the surface discharge. 1) an electrical current is stored in a capacitor; 2) a spectrally selective dielectric material is chosen based upon its atomic transition structure; 3) electrodes placed at either end on the dielectric material; 4) a backplane (current return) is run under the material and attached to the second electrode [8].

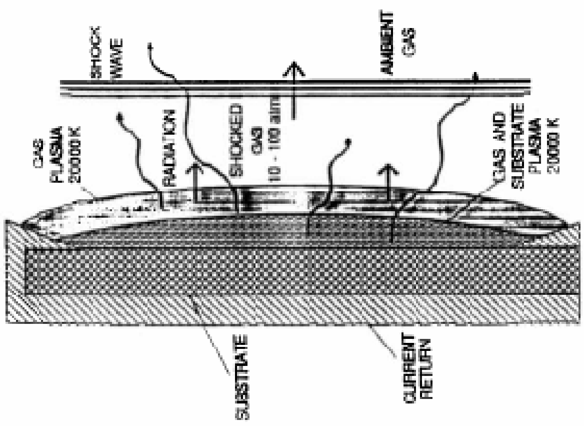

Figure 4. Surface Discharge Schematic

In operation, the capacitor is discharged releasing the stored energy with a plasma formed atop the dielectric material. This plasma excites the atoms within the dielectric material and they emit preferentially within their bound-bound states; hence spectrally enhancing the plasma emission. Typically, the plasma will consist of three states: 1) free-free; 2) free-bound, and; 3) bound-bound. Of these, bound-bound contributes greatest to the output. Figure 5 depicts the degree of spectral enhancement possible for a given dielectric material within a spectral region and Figure 6 shows the radiance as a function of temperature for various substrate materials. Notice how the substrate material has a direct contribution to the output energy of the plasma.

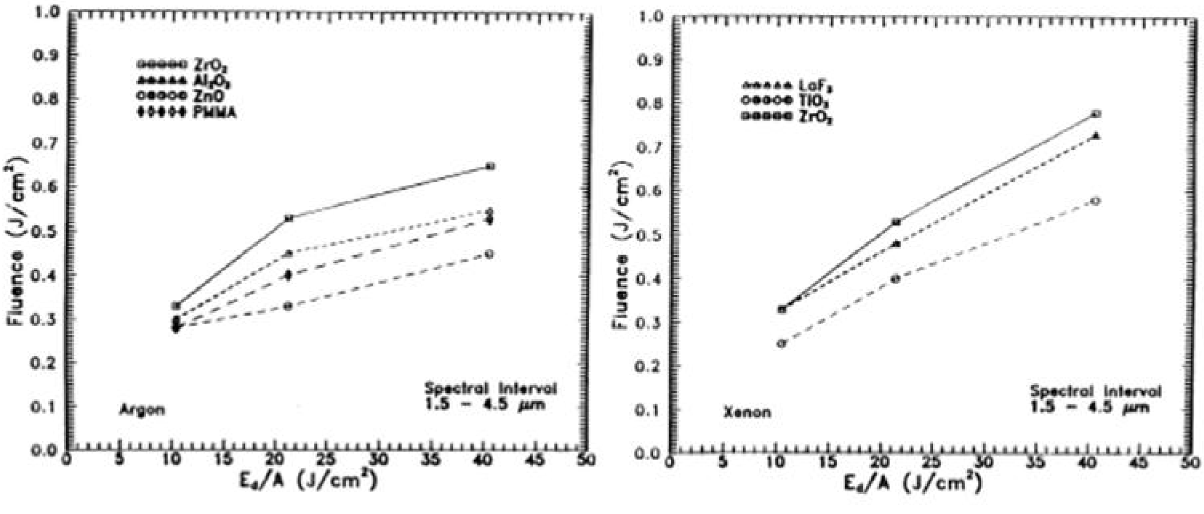

Figure 5. Degree of spectral enhancement as a function of substrate material [8]

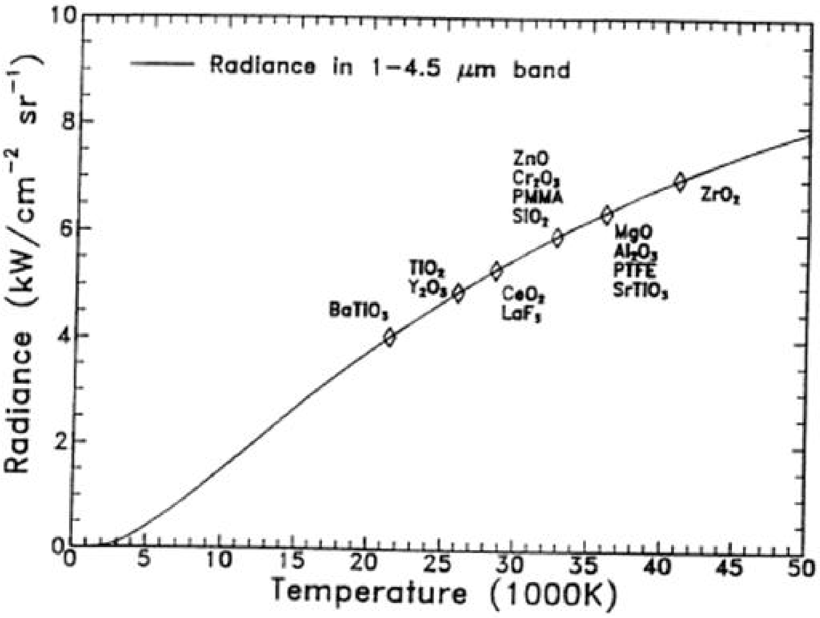

Figure 6. 1.5μm to 4.5 μm radiance for 14 substrates at 10 KV [8]

While the surface discharge did show much promise as an IRCM source, it, unfortunately came along with the advent of reliable missile warning sensors and IRCM lasers; hence, the dawn of Directed IRCM (DIRCM). The surface discharge remains a curiosity to this day, bypassed by the superior performance of lasers.

3.0 Directed Infrared Countermeasures (DIRCM)

With the advent of reliable, high angle accuracy missile warning sensors came Directed Infrared Countermeasures, or DIRCM. DIRCM systems employ several pieces of hardware in basically the same configuration. A typical DIRCM system will consist of several Missile Warning Sensors (MWS) to detect the threat launch; a turret containing a Fine Track Sensor (FTS), and; the IRCM source. In operation, the missile warning sensor (MWS) on the platform detects the threat missile launch. Threat position is localized to within a few pixels on this MWS. Next, the system processor instructs the turret to slew to the threat position where a fine track sensor (FTS) contained within the turret acquires the threat. Finally, the IRCM source transmits jamming energy to the threat.

In its earliest incarnation, DIRCM systems were lamp-based, with the lamp providing all-band output. In some cases these systems were referred to as Focused Infrared Countermeasures, or FIRCM systems. An early lamp-based FIRCM system is shown in Figure 7 [9]. In some cases a laser was used for the longest wavelength bands, thus, providing greater radiant output than the lamp within this wavelength region. An example of these early IRCM lasers consists of frequency doubled CO2 lasers, Figure 8. Their primary disadvantage was their inability to generate output within all IRCM bands. Rapid advances in non-linear materials enabled lasers to mature rapidly to all-band output, thus, replacing lamps and single-band lasers completely.

In present day IRCM, the laser is the heart of the DIRCM architecture and is available in various architectures. Figure 9 shows a present day Northrop Grumman AN/AAQ-24 DIRCM system; widely installed on multiple platforms. Here, the lamp port is no longer used and the laser is seen at the bottom of the turret.

Figure 7. Early Lamp-based DIRCM System (also known as FIRCM) [9]

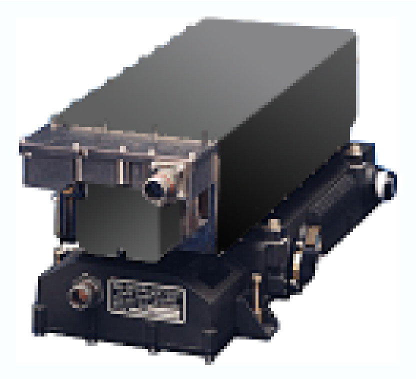

Figure 8. Frequency doubled CO2 laser for IRCM application [10]

Figure 9. Northrop Grumman AN/ALQ-24 DIRCM System [11]

The advent of high quality non-linear optical materials enabled solid state lasers to operate in all wavebands of interest, hence, comprising the total IRCM spectrum. These devices signaled a paradigm shift in IRCM away from omni-directional to highly-directional. Figure 10 depicts Northrop Grumman's VIPER all-band IRCM laser. Another interesting approach to IRCM lasers is offered in Figure 11 (SELEX Galileo) which utilizes a compact fiber-pumped fundamental stage.

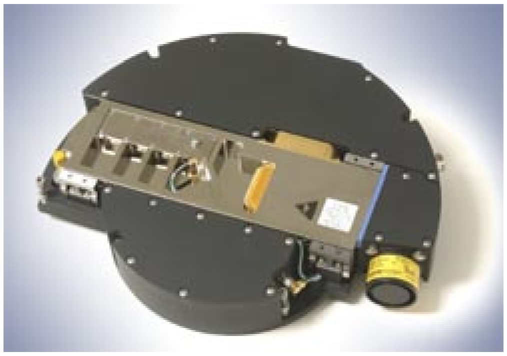

Figure 10. Northrop Grumman Viper Laser [12]

Figure 11. SELEX Model 160 IRCM Laser [13].

4.0 What's Next?

As threats evolve, and IRCM systems become more prolific, source technology must also evolve. Promising new technologies include Quantum Cascade Lasers (QCLs), Figure 11, Figure 12, and Figure 13; and Femtosecond lasers, Figure 14. QCLs have recently caused quite a stir in the IRCM community given their simple architecture, robustness, direct electrical-to-optical output, and all-band operation. QCL's can provide high wallplug efficiency, excellent beam quality, and a very compact size all at a very affordable price.

The quantum cascade laser (QCL) is a diode laser that is designed on the quantum mechanical level to produce light at the desired wavelength with high efficiency. Unlike traditional diode lasers, the device is unipolar, requiring only electrons to operate. Unlike typical interband semiconductor lasers that emit electromagnetic radiation through the recombination of electron-hole pairs across the material band gap, QCLs are unipolar and laser emission is achieved through the use of intersubband transitions in a repeated stack of semiconductor multiple quantum well heterostructures [14].

Within a bulk semiconductor crystal, electrons may occupy states in one of two continuous energy bands - the valence band, which is heavily populated with low energy electrons and the conduction band, which is sparsely populated with high energy electrons. The two energy bands are separated by an energy band gap in which there are no permitted states available for electrons to occupy. Conventional semiconductor laser diodes generate light by a single photon being emitted when a high energy electron in the conduction band recombines with a hole in the valence band. The energy of the photon and hence the emission wavelength of laser diodes is therefore determined by the band gap of the material system used [15].

A QCL however does not use bulk semiconductor materials in its optically active region. Instead it comprises a periodic series of thin layers of varying material composition forming a superlattice. The superlattice introduces a varying electric potential across the length of the device, meaning that there is a varying probability of electrons occupying different positions over the length of the device. This is referred to as one-dimensional multiple quantum well confinement and leads to the splitting of the band of permitted energies into a number of discrete electronic subbands. By suitable design of the layer thicknesses it is possible to engineer a population inversion between two subbands in the system which is required in order to achieve laser emission. Since the position of the energy levels in the system is primarily determined by the layer thicknesses and not the material, it is possible to tune the emission wavelength of QCLs over a wide range in the same material system.

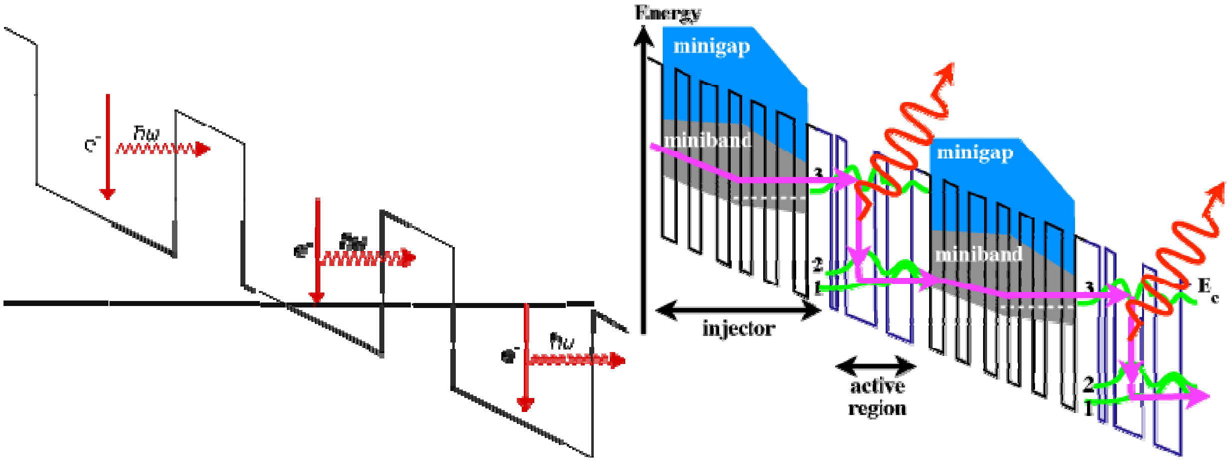

Figure 11. Quantum Cascade Laser Operation [14, 15]

Figure 12. Daylight Solutions QCL [16]

Figure 13. Cascade Technologies QCL [17]

Femtosecond lasers can provide tremendous peak power enabling new classes of directed IRCM to be explored [18, 19]. In this capacity these sources offer the potential for causing physical damage to the seeker or one of its elements, thus, defeating the threat. However, these sources must be explored with regard to effects at the dome, focal plane, and the corruption of the beam by atmospheric scattering and turbulence effects. Damage effects are promising with regard to defeating new generation, focal plane array-based threats and those using quasi-imaging architectures. But, as these sources are relatively new, this area needs to be explored in sufficient depth and with sufficient understanding of the physical processes involved to be considered viable. Some recent research has shown the potential for these sources to be used, and very dramatically, to defeat advanced threats. However, much research and development must occur before these sources can be considered.

Figure 14. Ultrafast Femtosecond Laser [19]

5.0 Summary and Conclusions

During the short time that IRCM has been in existence, source technology has evolved enabling new and exciting IRCM architectures to emerge. As threats advance and evolve, IRCM solutions must also advance to both keep pace and to leap ahead. It is the source that is at the foundation of an IRCM system and this device must be able to address threats on all fronts, of every nature, both existing and emerging. At both the most basic level of defeating a threat by disrupting the seeker logic to actually damaging the threat itself IRCM systems keep evolving. And pivotal to this evolution is the source.

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