Technologies

RAFAEL
ADVANCED DEFENSE SYSTEMS LTD.

OPTICAL COMPONENTS

Proven Reliability for all Applications



Introduction

Rafael Advanced Defense Systems Ltd. designs, develops, manufactures and supplies a wide range of high-tech systems for air, land, sea and space applications. Rafael was established as part of the Israeli Ministry of Defense more than 70 years ago and was incorporated in 2002. Rafael has created partnerships with leading aerospace and defense companies in Israel and overseas. Offset activities and industrial cooperation have been organized with over 20 countries world-wide. Over the last decade, international business activities have been steadily expanding across the globe by predicting the needs of future aerospace requirements worldwide and providing the technologies and systems required by our customers. Rafael's highly skilled and dedicated workforce tackles complex projects, from initial development, through prototype, production and acceptance tests. It provides customer service and support, upgrading existing systems and offering turnkey projects involving the transfer of basic technologies or complete production facilities.

Rafael is the largest employer in Northern Israel with approximately 8,000 employees and numerous subcontractors and service suppliers. Rafael is certified to AS9100:2009 ISO9001: 2008, ISO 17025, ISO 14001, OHSAS 18001, and complies with CMM and CMMI (level 3).

MANOR Advanced Defense Technologies Division develops, manufactures and offers a full range of optical components as well as propulsion systems, rocket motors naval decoys warheads, S&A systems, pyrotechnics devices, composite and smart materials for Rafael's systems and for domestic and international customers. The MANOR Advanced Defense Technologies Division is engaged in every aspect of product development and manufacturing activities, from specification and design to manufacturing and integrated logistics support. Comprehensive analytical tools and facilities are available in-house, covering all aspects of research, design, development, manufacturing, testing and simulation.

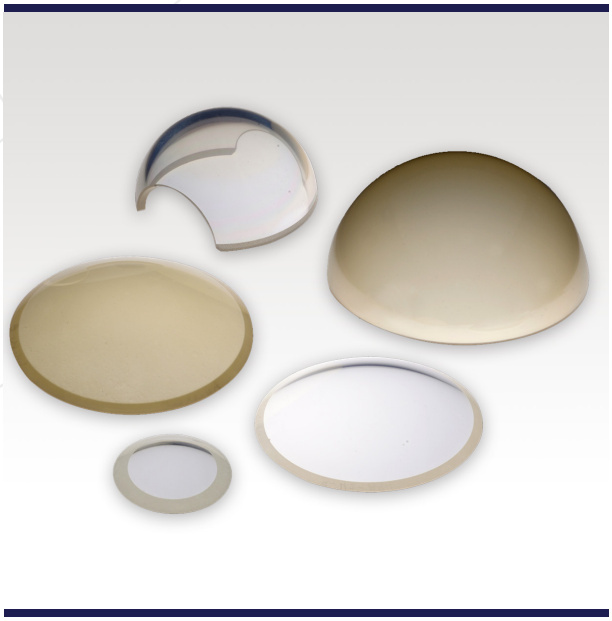


Overview

Founded in 1974, Rafael's Optical Components Center (ROCC) benefits from over four decades of extensive design and engineering experience. Its products have been tested and proven, under the toughest operating conditions in both military and commercial systems. Customers include: Israel Defence Forces (IDF), Israel Air Force (IAF), Northrop, Israel Aircraft Industries (IAI), El-Op, SCD, FINMECCANICA, DIEHL and many others.

The center offers a full range of services, able to meet your every design requirement, no matter how special. ROCC can assist in every stage of the project: from feasibility studies and definition of specs, through advanced design and prototype development, to full scale production, including testing and quality assurance. ROCC's extensive experience and the supporting facilities yield state of the art products at competitive prices and ensure on-time delivery.





Applications

Rafael's Optical Components Center (ROCC), develops and produces a full range of optical components for a variety of applications including

- Missiles
- Various dedicated payloads (air, sea and land platforms)
- Sensors
- Guided munitions
- High energy systems
- Civil applications



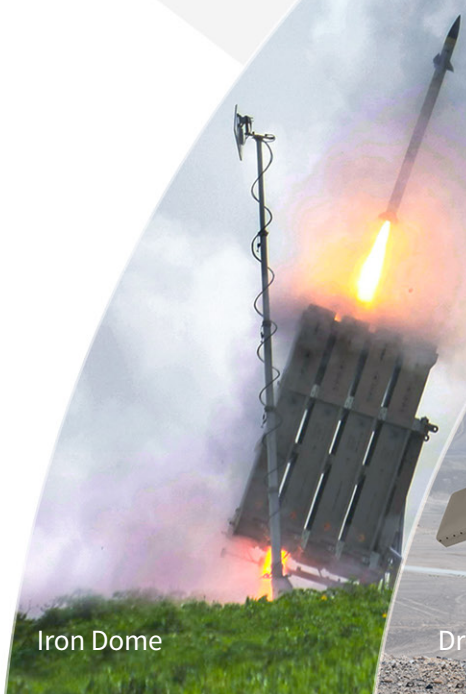
Litening



Spice



Spike



Iron Dome

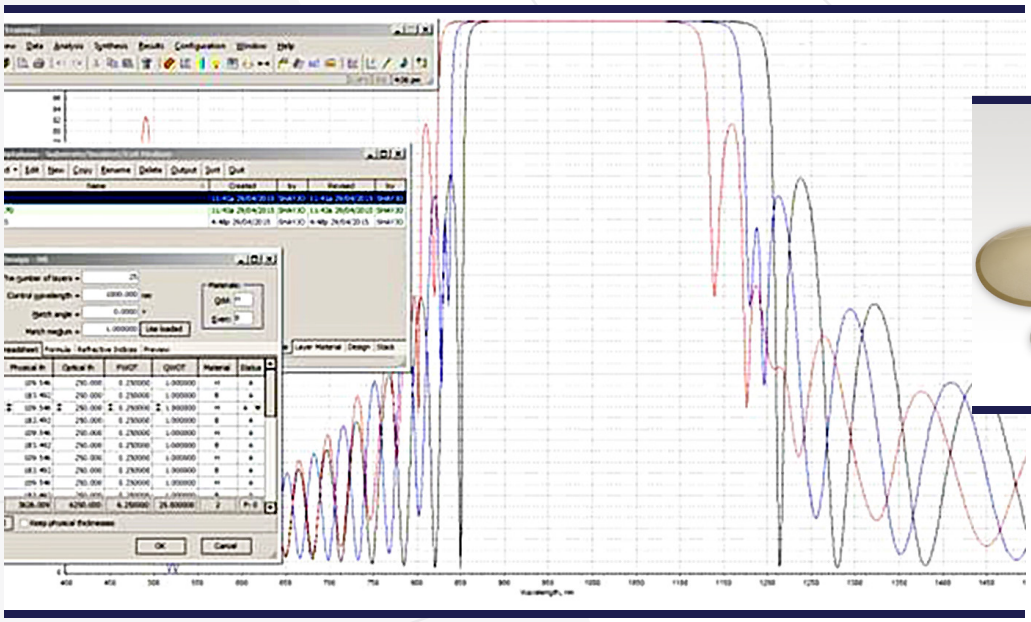


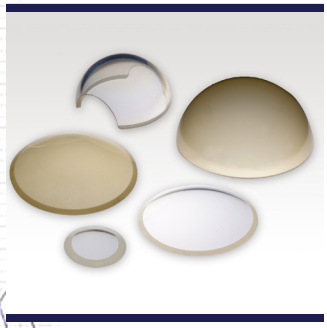
Drone Dome

* Partial Examples

Design and Development

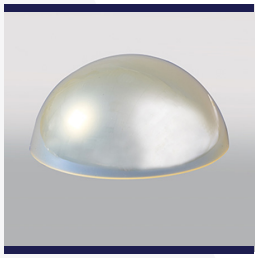
Rafael's Optical Components Center designs and develops a variety of optical components. The center has more than 40 years experience in the design and development of hundreds of different optical components and over a dozen optical assemblies using several computer aided design and simulation software. A multi-disciplinary engineering and research team designs and develops highly complex components based on the most demanding specifications of our customers. Rapid prototyping enables customers to perform tests at relatively early stages of the development.

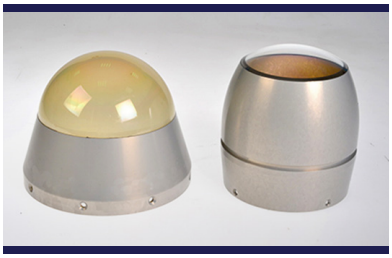










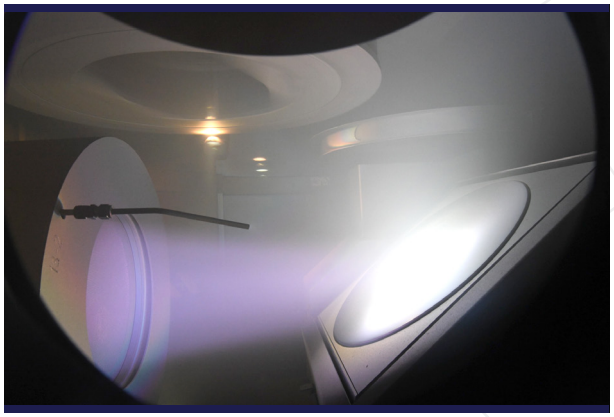


Production

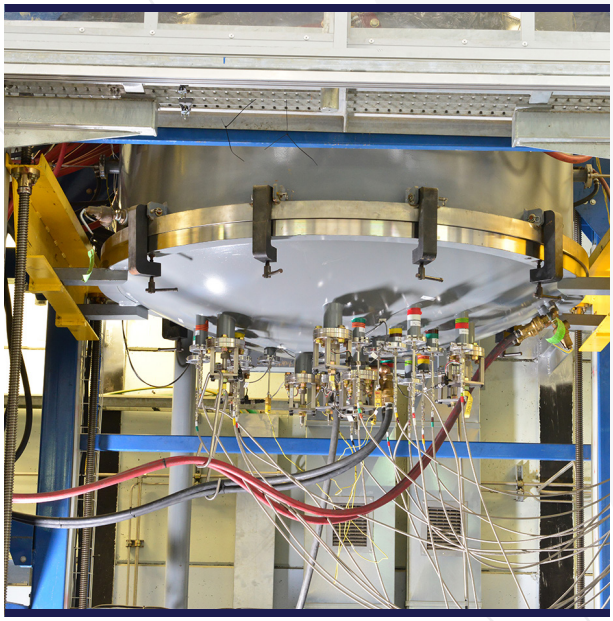
Rafael's Optical Components Center production plant is equipped with state of the art infrastructure including advanced CVD, IAD and IBS systems.

Our production lines include:

- FLIR grade and multispectral grade CVD ZnS
- Optical elements, up to Ø50cm, made of a vast variety of materials (glasses, Ge, Si, ZnS, ZnSe, CaF_2, As_2Se_3, Sapphire and more) with coatings for all spectral ranges (VIS, NIR, MWIR, FLIR)
- Replicated mirrors
- Assembly of optical components: bonding, cementing and sealing







Testing

Testing Facilities and Quality Assurance

Rafael's Optical Components Center benefits from the highly advanced infrastructure of Rafael, and from collaboration with the Technion-Israel Institute of Technology. This includes materials & optical testing laboratories, Rafael's environmental engineering center, surface and interface characterization laboratories, polymers and adhesives testing and evaluation. All activities are supported by our optomechanical and materials engineering experience. Quality assurance is especially critical for optical components and is an integral part of development and production activities. The center is fully qualified by Israel Defense Forces and major US manufacturers. All activities follow the guidelines of AS-9100, ISO 9001: 2000, ISO 14001 and ISO 18001standards.



ZnS Domes and Windows

Rafael's Optical Components Center is a leading producer of domes, windows and lenses of high optical quality zinc sulfide (ZnS), used in FLIR imaging and in various missiles. ZnS is a polycrystalline, infra-red transmitting material, produced by the chemical vapor deposition (CVD) process. Its main advantages compared with other infra-red transmitting materials are: wide transparency range (visible through 3-5µm and 8-12µm IR ranges), hardness, strength, low refractive index and cost effectiveness. ZnS transparency is extended to the visible light range by applying hot isostatic pressure (HIP) treatment. Material can be supplied SMTY in sizes up to 600X400X30mm or as pre-polished or polished domes, windows or lenses.

Multispectral ZnS

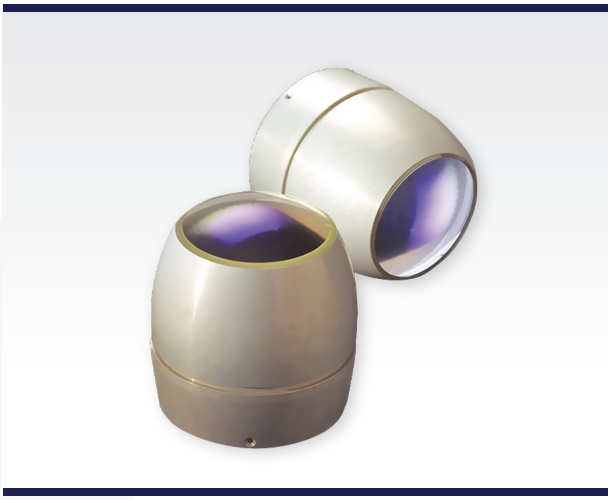
Structure	Cubic
Grain Size	20-50 [µm]
Bulk absorption coefficient @ 10.6µm	0.2 [1/cm]
Temperature change of refractive index @ 10.6µm	4.1X10-5[1/K]
Refractive index @ 10.6 µm & 20°C	2.192±0.002
Refractive index inhomogeneity @ 10.6 µm	< 0.0001
Transmission for 4mm th. sample @ 570nm	>67%
Transmission for 4mm th. sample @ 750nm	>69%
Average transmission for 4mm th. sample @ 3-5µm	>74%
Maximum inclusion size	<0.1mm
Thermal conductivity @ 20°C	27.2 [J/Kms]
Specific heat	0.515 [J/gK]
Linear expansion coefficient @ 20°C	6.5X10-6[1/K]
Young's modulus	65 [GPa]
Flexural strength (modulus of rupture)	70 [MPa]
Hardness (Knoop, 50gr. load)	140-160
Density	4.09 [gr/cm^3]
Poisson's ratio	0.28

ZnS Domes and Windows

CVD Grade ZnS

Structure	Cubic
Grain Size	2-6 [µm]
Bulk absorption coefficient @ 10.6µm	0.2 [1/cm]
Temperature change of refractive index @ 10.6µm	4.1X10-5[1/K]
Refractive index @ 10.6 µm & 20°C	2.192±0.002
Refractive index inhomogeneity @ 10.6µm	< 0.0001
Average transmission for 4mm th. sample @ 8-13µm	>68%
Thermal conductivity @ 25°C	16.7 [J/Kms]
Specific heat @ 25°C	0.469 [J/gK]
Linear expansion coefficient @ 100°C	7.3X10-6[1/K]
Young's modulus	73 [GPa]
Flexural strength (modulus of rupture)	102 [MPa]
Hardness (Knoop, 50gr. load)	200-230
Density	4.08 [gr/cm^3]
Poisson's ratio	0.29





Typical Performance

The following are typical examples of our capabilities. Customized solutions are also available.

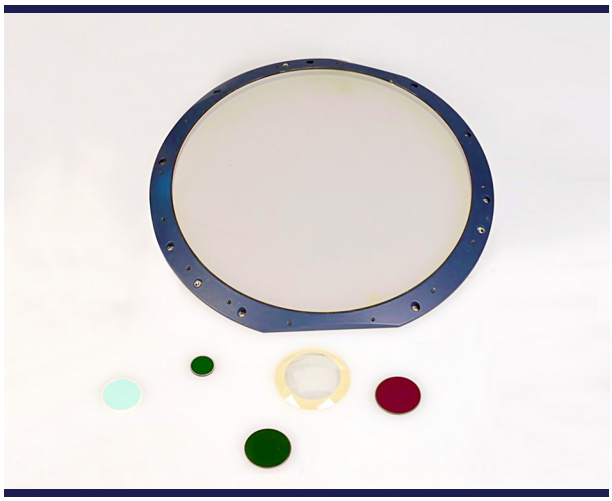
Anti-Reflection Coatings-Infrared

Low reflectivity coatings for one or more spectral ranges and for special angular or durability requirements can be provided on internal or external surfaces of most optical substrate materials.

Spectral range	Spectral Performance	Substrate
3 - 5µm	$T_{av} \geq 98\%$, $R_{av} \leq 0.5\%$	Germanium, Silicon, Multispectral grade ZnS, ZnSe, Sapphire, CaF2
8 - 11µm	$T_{av} \geq 95\%$, $R_{av} \leq 0.5\%$	ZnS**
8 - 12µm	$T_{av} \geq 97\%$, $R_{av} \leq 0.5\%$	Germanium, ZnSe, As2Se3
8 - 14µm	$T_{av} \geq 96\%$, $R_{av} \leq 1.0\%$	Germanium, ZnSe

* Durability per MIL-C-48497A.

** Rain Erosion per OCLI spec # 6040012



Anti-Reflection Coatings-Multispectral

Spectral range	Spectral Performance	Substrate
3-5µm+8-12µm	3-5µm: T_{av}≥85% 8-12µm: T_{av}≥92%	Multispectral ZnS
Visible+1.064µm	T_{av}≥85% Rav≤0.5%	Glass, Sapphire
Visible+3-5µm	VIS: T_{av}≥95% 3-5µm: T_{av}≥98% R_{av}≤1%	Multispectral ZnS CaF_2
Visible+1.064µm +3-5µm	T_{av}≥96% R_{av}≤1.5%	Multispectral ZnS
Visible+1.55µm +8-12µm	VIS: T_{av}≥85% 1.55µm: T≥92% 8-10µm: T_{av}≥95%	Multispectral ZnS
1.064µm +1.57µm +3-5µm	T_{av}≥96% R_{av}≤1.5%	Multispectral ZnS
Visible+NIR+8-12µm	VIS+NIR: T_{av}≥85% 8-12µm: T_{av}≥90%	Multispectral ZnS
Visible+NIR+3-5µm +8-12µm	VIS: T_{av}≥80% NIR: T_{av}≥80% 3-5µm: T_{av}≥90% 8-12µm: T_{av}≥85%	Multispectral ZnS
NIR+3-5µm	T_{av}≥96% R_{av}≤1.5%	Multispectral ZnS

Durability: Humidity, adhesion, moderate/ severe abrasion, temperature, as per MIL-C-48497A, salt spray as per MIL-C-675C, Rain Erosion per OCLI spec # 6040012, upon request

* Transmittance values are given for the coated optics. Reflectance values are given per surface.
* Transmittance values for multispectral ZnS may vary with thickness.

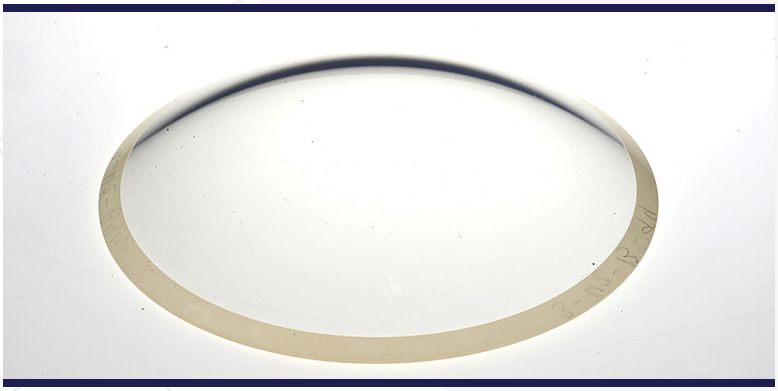
Anti-Reflection Coatings

WIDE AOI (Angle of Incidence)

Typical performance of coatings for a single IR band

Spectral range	AOI	Spectral Performance	Substrate
3-5µm	0-70˚	@AOI 0-25˚ R_{av}≤0.5% @AOI 25-45˚ R_{av}≤1% @AOI 55-65˚ R_{av}≤4%	Germanium Silicon
3-5µm	20-55˚	R_{av}≤3%	Sapphire





Filters Infrared (8-14µm)

All filter types: short - and long-pass filters, as well as wide- and narrow-band-pass filters can be designed and manufactured to meet specific needs for the far infra-red, on most optical materials.

Specific optical and durability/ functionality requirements, such as operation at cryogenic temperatures, high blocking or non- perpendicular incidence angle can be readily met. Complex objects can be coated.

Filter Type	Spectral Performance	Substrate
Long-wave pass	T_{av}≥95% @λ<λcuton T_{av}≤0.2%	Germanium, ZnS
Wide band-pass	In band: T_{av}≥95% Out of band: T_{av}≤0.2%	Germanium, ZnS
	Peak transmission ≥85% for half band width of 1.5-3%	Germanium

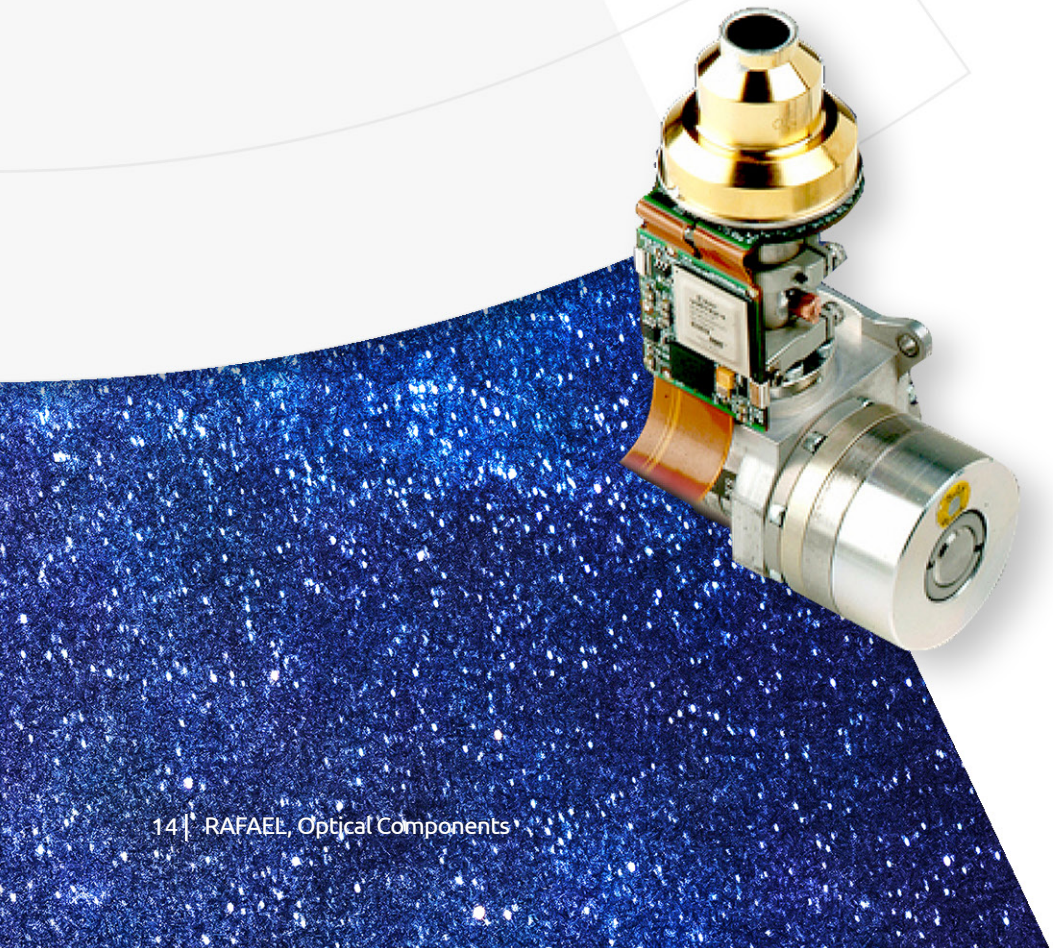
Durability: Humidity, adhesion, moderate abrasion, as per MIL-C-48497A

Filters Infrared (3-5µm)

All filter types: short - and long-pass filters, all as wide- and narrow-band-pass filters can be designed and manufactured to meet specific needs for the mid infra-red, on most optical materials. Specific optical and durability/ functionality requirements, such as operationat cryogenic temperatures, high blocking or non- perpendicular incidence angle can be readily met. Complex objects can be coated.

Filter Type	Spectral Performance	Substrate
Shortwave pass or Long-wave pass or Wide-band pass	λ cutoff/cuton: any λ in the 3-5µm range In band: T_{av}≥95% Out of band: T_{av}≤0.2%	Sapphire Germanium Silicon Quartz
Narrow band-pass	λ cutoff/cuton: any λ in FWHM BW 0.2-0.3µm In band: T_{av}≥90% Out of band: T_{av}≤0.5%	Sapphire Germanium Silicon

Durability: Humidity, adhesion, moderate abrasion, as per MIL-C-48497A



Filters Visible and Near IR

All filter types: short - and long-pass filters, as well as wide- and narrow- band-pass filters can be designed and manufactured to meet specific needs for the visible and near infra-red, on most optical materials. Specific optical and durability/ functionality requirements, such as operation at cryogenic temperatures, high blocking or non- perpendicular incidence angle can be readily met. Complex objects can be coated.

Spectral Range	Filter Type	Spectral Performance	Substrate
Visible	Long-wave pass	In band: T_{av}≥92% @λ<λcuton T_{av}≤1%	CaF_2
Visible+NIR	Long-wave pass	In band: T_{av}≥90% @λ<λcuton T_{av}≤1%	Quartz
Visible+NIR	Short-wave pass	In band: T_{av}≥92% @λ<λcutoff T_{av}≤1%	Glass, Quartz
1.064μm	Narrow band- pass	Tpeak≥85% FWHM~20nm Tout of band≤1%	Glass, Sapphire
Visible	Wide band- pass	In band: T_{av}≥92% FWHM~150nm Tout of band≤2%	Glass, Sapphire, Quartz
NIR	Short-wave pass or Wide band- pass	In band: T_{av}≥87% @λ>λcutoff T_{av}≤0.05% @ λ<λcuton T_{av}≤0.5**%**	Glass

Durability: Humidity, adhesion, moderate abrasion, as per MIL-C-48497A

Filters Dual Band

Spectral Range	Spectral Performance	Substrate
1.064μm +3-5μm	@1.064μm: FWHM=25±5nm, Tpeak≥60% @3-5μm: T_{av}≥80%, Out of band T_{av}≤0.5%	Sapphire
NIR +3-5μm	@NIR T_{av}≥87% @3-5μm T_{av}≥80 Out of band T_{av}≤5%	Silicon

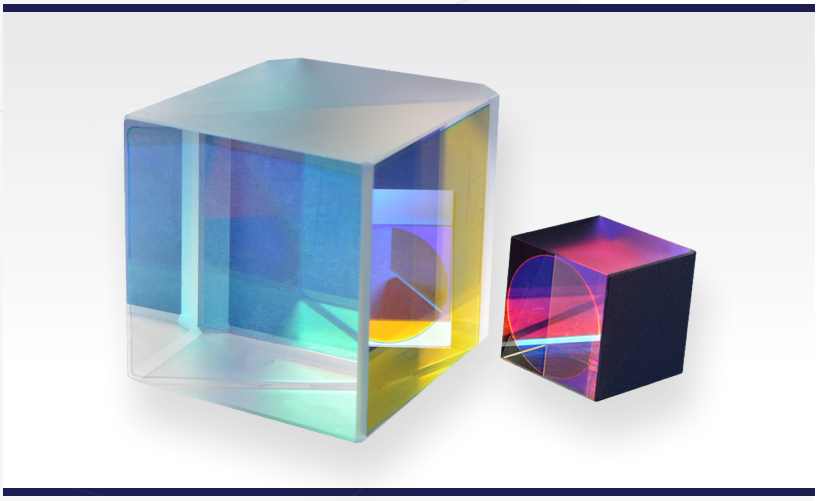
Durability: Humidity, adhesion, moderate abrasion, as per MIL-C-48497A

Dichrolc Coatings and Beam Splitters

Coatings with desired performance characteristics in more than one spectral band, as well as cemented and non- cemented beamsplitters are readily available.

Spectral range	Spectral Performance	Substrate
Visible+3-5µm	VIS: R_{av}≥80% 3-5µm: T_{av}≥90% Cemented, 45˚	CaF_2
Visible+8-12µm	VIS: T_{av}≥90% 8-12µm: R_{av}≥85% AOI=45˚	Glass
Visible+3-5µm	VIS: T_{av}≥89% 3-5µm: R_{av}≥90% AOI=45˚	Quart
Visible	T_{av}=20-40% R_{av}=60-80% Cemented, 45˚	Glass
Visible+1.064µm	VIS: T_{av}≥83% 1.064µm: R≥95% Cemented, 45˚	Glass

Durability: Humidity, adhesion, moderate abrasion, as per MIL-C-48497A
High LIDT options also available upon request



Transparent Conductive Coatings

High performance transparent conductive coatings are available for the far infrared, near infrared and visible range for various substrates. Coatings tailored for specific requirements can be designed and manufactured. Free-standing metallic grids and printed meshes are also available for windows as well as domes.

Spectral Range	Surface Resistance [Ω/□]	Average Transmittance [%]	Substrate
Visible	5±1	>93	Glass, Sapphire
Visible+NIR	8±2	>90	Glass, Sapphire
1.064µm	10±2	>95	Glass, Sapphire
3-5µm	30±5	>75	Glass, ZnS
8-12µm	15±2	>70	ZnS

Durability: Adhesion, abrasion, humidity and temperature as per MIL-C-48497A

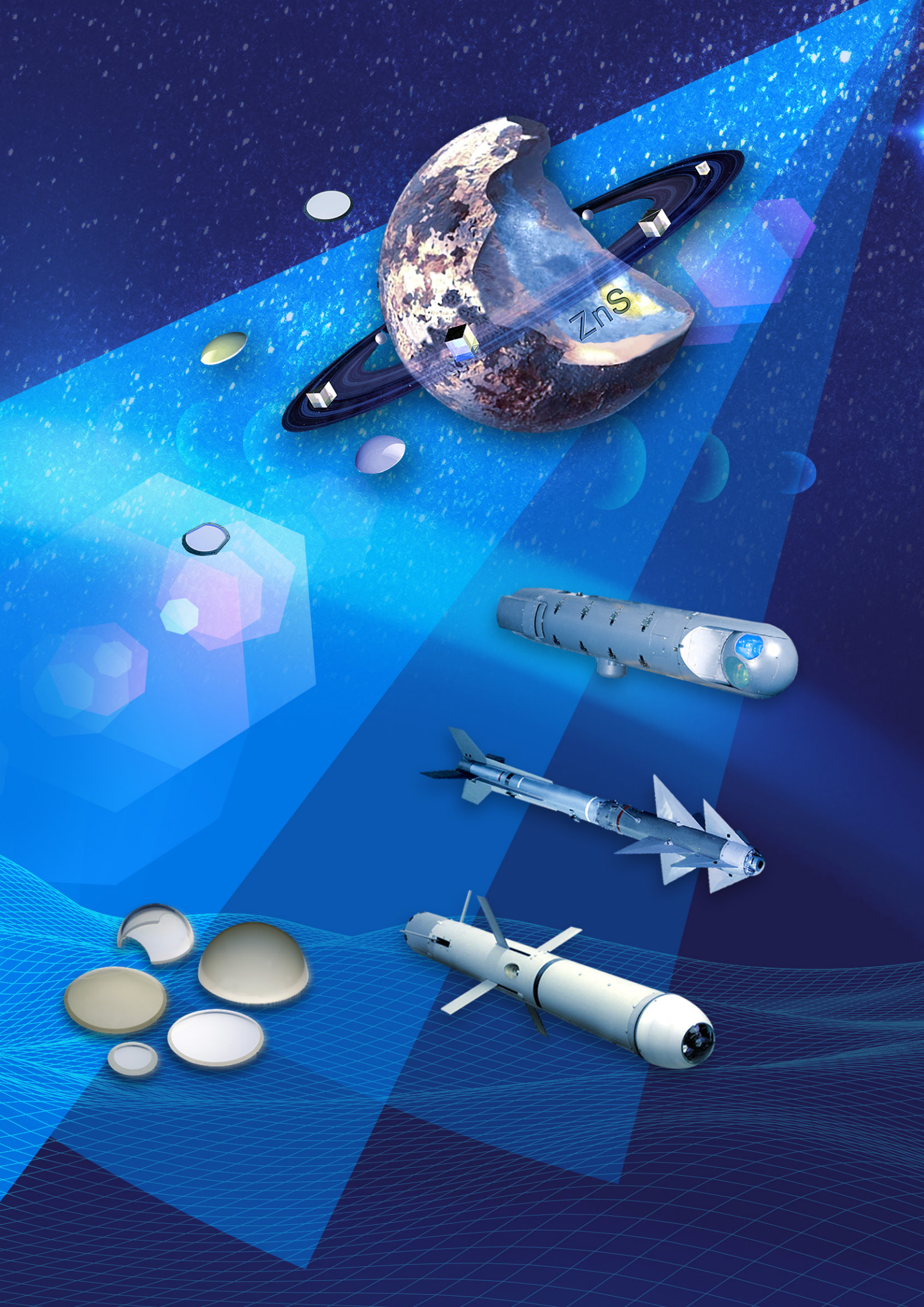
Dual Band Transparent Conductive Coatings

High performance transparent conductive coatings are available for dual spectral bands. Free-standing metallic grids and printed meshes are also available for windows as well as domes.

Spectral Range	Surface Resistance [Ω/□]	Spectral Performance	Substrate
Visible+3-5µm	100±10	VIS: T_{av}≥80% 3-5µm: T_{av}≥85%	ZnS, Sapphire
Visible+NIR+3-5µm	40±5	VIS+NIR: T_{av}≥80% 3-5µm: T_{av}≥70%	ZnS, Sapphire
Visible+NIR	8±2	T_{av}≥90%	Glass, Sapphire
Visible+NIR+8-12µm	40±5	VIS+NIR: T_{av}≥80% 8-12µm: T_{av}≥40%	ZnS

Durability: Humidity, adhesion, moderate abrasion, as per MIL-C-48497A


RAFAEL
Raytheon


ZnS

RAFAEL

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