Executive Summary for ERG1/RTP109.004/001

The cost of optics is often a significant proportion of the total cost of thermal imaging and dual waveband sensor systems. Costs of IR detectors have effectively reduced and system costs have reduced even more because there is no longer the need for a mechanical scanning subsystem. However, the optics cost has become a higher proportion of the overall system cost. It is desirable to reduce the cost of infrared optics to enable more affordable sensors to be realised, this programme was initiated to address this issue. There was also a requirement to assess the suitability of any new materials for use in space.

Five nations within the EDA community (formerly EUROPA) – Belgium, Italy, Spain, Sweden and UK - agreed to fund a programme to investigate ways of reducing the cost of IR optics based on a production run of 500 units over two years. A consortium of seven partners from the five nations – CSL (Be), Galileo Avionica (It), INDRA (Sp), Saab and FLIR Systems (Sw), Qioptiq and QinetiQ (UK) – was formed and successfully bid to conduct the work. The programme was managed by QinetiQ. The programme started in February 2004 and was scheduled to run for four years.

This programme has concentrated on optics for thermal imaging sensors where optics are expensive. Funding constraints did not allow a broader programme covering a wider range of wavebands, e.g. Short Wave Infrared or a wider range of sensor systems e.g. hyperspectral sensors. Likewise reflective optics were not considered because their application is generally limited to narrow FOV systems and so would not be relevant to IR sensor systems in general.

The methodology adopted within the programme was to:

- Define specifications for three dual field of view IR sensor systems, one MWIR, one LWIR and one Dual Waveband
- Develop designs of optics for these three systems using conventional optical materials and processes – the Reference lens designs.
- Develop a Cost Model to enable assessment of savings that might be made and generate a relative base line cost for each of the Reference lenses
- Conduct research work into techniques for reducing the cost of optics, techniques investigated included:
  - New materials, including suitability for space applications
  - Moulding and embossing processes
  - Wavefront Coding techniques
  - “Moth-eye” type AR coatings
- Perform redesigns of the lenses using knowledge gained during the programme – the Redesigned lenses
- Calculate costs for the Redesigned lenses and compare with the Reference lenses, also estimate any reductions in size and weight
- Fabricate the Redesigned MWIR and LWIR lenses for evaluation – referred to as MWOS and LWOS respectively – and sample DWB components.

Key outputs from the programme are as follows:

- A Cost Model has been developed to enable relative costs of optical systems to be estimated.
- Chalcogenide materials that can be moulded offer a route to lower cost optics when considering production run quantities
- Moulding techniques for chalcogenides were investigated, nickel plated stainless steel moulds were unsuccessful – the nickel delaminated – more work is required to overcome this problem. More success was achieved using glass moulds, again more work is needed to optimise this process.
- “Moth-eye” type AR coatings are feasible these could be embossed, incorporated in the mould design or produced by direct ablation using an excimer laser.
- Chalcogenide materials are suitable for space applications.
Current polymer materials have too much transmission loss in the infrared to be used as stand alone components for high performance systems. However, they could potentially be used as laminates on IR transmitting substrates.

Wavefront Coding (WFC) provides an added level of flexibility to the optics design. WFC can be introduced by incorporating a cubic phase pattern on the surface of an element in the optical system or by displacing optical elements orthogonal to the optical axis to deliberately induce coma. Reconstruction algorithms have been demonstrated to give good reconstructed imagery across the field of view even with a single element optical system.

MWIR, LWIR and Dual Waveband (MWIR + LWIR) optical systems were designed that incorporated several chalcogenide elements and several diffractive surfaces. Measurements on the MWIR and LWIR optics that were fabricated using these designs (and DWB samples) have shown that this is a viable approach to high performance IR optics that will give cost, size and weight savings over conventional designs. Estimates of the savings for production volumes of 500 units over two years are given in the table below:

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>Size</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>LWOS</td>
<td>40%</td>
<td>16%</td>
<td>22%</td>
</tr>
<tr>
<td>MWOS</td>
<td>18.5%</td>
<td>48%</td>
<td>30%</td>
</tr>
<tr>
<td>DWB</td>
<td>38%</td>
<td>6%</td>
<td>36%</td>
</tr>
</tbody>
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Adopting Wavefront Coding could result in further savings, for example just eliminating the need for a focussing mechanism will result in further cost savings of >10%. The greater design flexibility that results from using WFC could result in less elements being required and so even greater savings.

This programme has successfully demonstrated approaches to reducing the cost of IR optics. Techniques to mould complete IR optical elements – incorporating “moth-eye” type AR coatings – have been shown to be feasible with more development. Inclusion of a WFC surface provides the possibility of a moulded single element optical system that could provide sufficient performance for many IR sensor applications, e.g. a hand-held sight. With appropriate funding, these technologies could be ready for exploitation within two or three years.