Infrared Physics & Technology 53 (2010) 33–36

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

High efficiency antireflection coating in MWIR region (3.6–4.9 μm) simultaneously effective for Germanium and Silicon optics

Meenakshi Bhatt *, B.B. Nautiyal, P.K. Bandyopadhyay

Instruments Research and Development Establishment, Dehradun, India

ARTICLE INFO

Article history:
Received 31 December 2008
Available online 28 August 2009

Keywords:
Antireflection coating
Multisubstrate
MWIR region
Environmental test
Cryopump
RGA

ABSTRACT

Antireflection coatings have critical importance in thermal imaging system working in MWIR region (3–5 μm) since optics of high refractive index materials are used. Germanium (Ge) and Silicon (Si) optics are used extensively in the MWIR thermal systems. In this paper a study has been carried out on the design and fabrication of multi-substrate antireflection coating effective for Germanium and Silicon optics in MWIR (3.6–4.9 μm) region. The wave band 3.6–4.9 μm is chosen for the reported work because detector system used in MWIR region has a band selection filter effective in the same wavelength region and atmospheric transmission window in MWIR region is effective in 3–5 μm spectral band. Comprehensive search method was used to design the multilayer stack on the substrate. The coating materials used in the design were Germanium (Ge), Hafnium oxide (HfO_2) and Y-Ba-Fluoride (IR-F625). The fabrication of coating was made in a coating plant fitted with Cryo pump system and residual gas analyzer (RGA). The evaporation was carried out at high vacuum ($2–6 \times 10^{-6}$ mbar) with the help of electron beam gun system and layer thicknesses were measured with crystal monitor. The result achieved for the antireflection coating was 98.5% average transmission in 3.6–4.9 μm band for Germanium and Silicon optics. This work will be helpful in reducing the plant operation time, material and power consumption, as two different kinds of optics are simultaneously coated in a single coating cycle.

1. Introduction

Most targets of military interest, vehicles, troops, airfields, factories differ from the general terrain either in temperature or emissivity or both. They have different radiating characteristics which are difficult to camouflage and which can readily be seen by thermal systems. In order to detect hot objects, the 3–5 μm window is found to be most suitable and it is one of the important atmospheric transmission window used for thermal imaging [1,2]. In MWIR instrumentation, optics of both Germanium and Silicon materials, are used. Antireflection coating is a critical issue for infrared optics in order to increase transmission for use in high indexed IR optics materials. MWIR is used for identification under all typical environmental conditions including fog, artic, tropical, desert, oil, sandstorm and maritime [3].

Pure n-type Germanium has good transmission characteristics and is available for use as an IR component material. The chemical inertness and insolubility of Germanium render it a potential material for use as a window and optics material [4]. The high degree of hardness and mechanical strength of the material make it an ideal candidate for applications in thermal systems where ruggedness is a prime factor [2]. Germanium optics can be used both in MWIR as well as LWIR region and some work is reported in the Journals for dual band antireflection coating on Germanium in these two regions [5–7]. Silicon is another IR optical material easily available with large quantities and dimensions with high purity to suit most electro-optical application. Its transmission spectrum from 3 to 5 μm is free from major absorption. Silicon's high refractive index, low dispersion and easy fabrication make it a very useful optical component. On the other hand, its surface hardness, robust mechanical strength along with non-hydroscopic and non-toxic properties suits as a strong candidate for optical element in 3–5 μm region [2,4]. Some work is reported in the Journals for Silicon antireflection coating also [8,9].

This paper reports design and fabrication of high efficiency multi-substrates antireflection coatings on Germanium and Silicon substrate in MWIR region (3.6–4.9 μm).

2. Coating design

The design of antireflection coating is based on comprehensive search method [10]. In this method the desired characteristic (transmission/reflection) are determined by optimizing the layer thicknesses of high and low refractive index layers. Selection of

* Corresponding author.
E-mail addresses: meenakshi_phy@irde.res.in, meenakshi09phy@gmail.com (M. Bhatt).

1350-4495/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.infrared.2009.08.006

Table 1
Physical thicknesses of different coating materials on Germanium and Silicon substrates.

Layer no.	Coating material	Refractive index (at 4.0 μm)	Physical thickness (nm)
1	IR-F625	1.44	423
2	Hafnium oxide	1.88	141
3	IR-F625	1.44	211
4	Germanium	4.00	96
5	IR-F625	1.44	129
Germanium or Silicon substrate			Massive

coating materials is based on their refractive index values, physical stability characteristics, their transparency in the desired wavelength regions and thermal expansion coefficients. In the design consideration, attempts have been made to establish a durable coating design without use of Thorium fluoride (ThF_4). Thorium fluoride was replaced because of its radioactive property. Three materials i.e. MIRA, IR-F900 and IR-F625 commercially available from M/S Umicore Materials AG were experimentally tried out for durable low refractive index material. IR-F625 was found as suitable choice for low refractive index material. The coating material chosen was Germanium as high index, Hafnium oxide as medium index and IR-F625 as low index. IR-F625 (transparency range 0.2–16 μm) is a potential low index (1.44 around 3–5 μm) IR (Infra Red) coating material with melting point 1250 °C. The chemical formula of this material is Y-Ba-Fluoride and density 5 g/cm^3. Hafnium Oxide is used as a bonding layer between two low indexed layers of IR-F625. The best possible design for Germanium and Silicon antireflection coating was evaluated from lowest possible value of merit function (with minimum possible number of layers, their refractive indices and corresponding optimized optical thicknesses). Table 1 shows the physical thicknesses of different coating materials on Germanium and Silicon multi-substrate antireflection coating. The theoretical transmission curve with respect to wavelength for antireflection coating on Germanium and Silicon substrate is shown in Fig. 1.

3. Experimental method

The multilayer stack designed for the multi-substrate antireflection coating on Germanium and Silicon substrate was fabricated using electron beam evaporation system in Symphony 9 (supplied by M/S Tecport Optics Inc.) vacuum coating plant. In this plant the cryo pump is used to minimize water vapour in the vacuum process and residual gas analyzer (RGA) system of the plant monitors the gases present in the system during deposition. Film adhesion is improved by elimination of oil diffusion pumps and by reduced back streaming from oil-sealed roughing pump. This kind of pump ensures oil free deposition. The residual gas analyzer (RGA) measures the partial pressures of gases in a mixture and during deposition it shows the amount of gas present in the system. The RGA helps to identify the presence of unwanted gases during deposition and with cryo pump system presence of water vapour during coating process was considerably reduced. The substrates were cleaned using ultrasonic cleaning process followed by vapour degreaser cleaning. Inside the vacuum chamber the optics were subjected to ionic cleaning for 30 min with the help of End-Hall ion gun. The evaporation took place at the working vacuum range $6\text{–}2 \times 10^{-6}$ mbar for Germanium and IR-F625. For Hafnium oxide the evaporation took place at the working vacuum range $4\text{–}2 \times 10^{-4}$ mbar in presence of oxygen gas. The rate of evaporation in case of IR-F625 was 8 Å/s and for Germanium 4 Å/s and for Hafnium oxide 3 Å/s.

The job was rotated with planetary rotation inside the chamber for uniformity. The substrate was heated up to 200 °C (with tolerance ±5 °C) for 2 h inside the vacuum chamber. Germanium was coated at substrate temperature below 200 °C to avoid absorption [11]. The substrate temperature during deposition was maintained at 200 °C (±5 °C). The coating was deposited on very thin micro slides of thickness 0.1 mm and it was found that there was negligible bending observed in the micro slide which confirms that both the film structure have very low stress [9].

4. Results and discussion

The samples taken up for this work were 25 mm diameter polished Germanium and Silicon flat substrates with 4 mm thickness. The coated samples of Germanium and Silicon were measured for transmission with M/S Perkin Elmer supplied Fourier transform infrared spectrophotometer of model GX-Optics. The experimental transmission curve with respect to wavelength for Germanium and

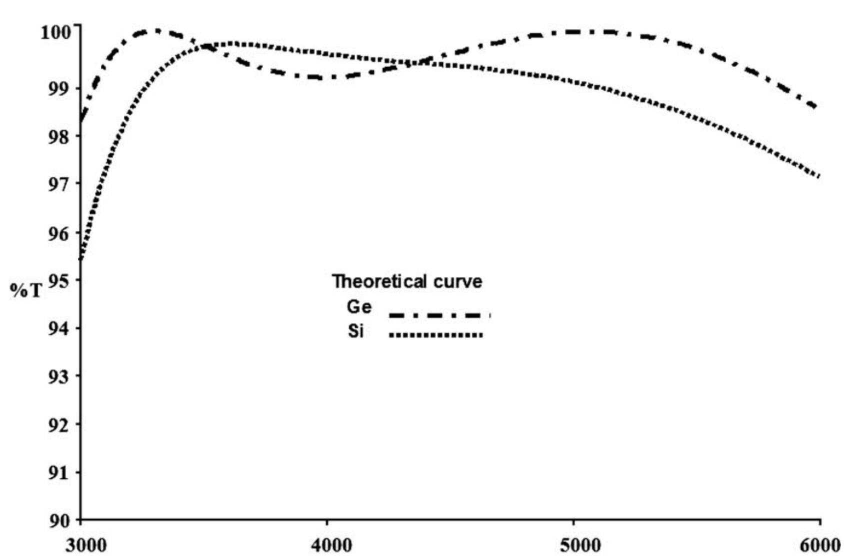

Fig. 1. Theoretical transmission curve with respect to wavelength for antireflection coating on Germanium and Silicon substrate.