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Infrared optical properties of silica aerogel substrates

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In this letter, we report the infrared optical properties of a novel silica aerogel substrate. The properties were measured at room temperature using spectroscopic ellipsometry in the wavelength range from 8 to 14 µm. The measurements gave a refractive index in the range 1.01 to 1.09 and an extinction coefficient variation between approximately 0.0096 to 0.0104. These results confirm the effectiveness of using silica aerogel as a substrate for antenna-coupled microbolometer detectors.

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Keywords: Silica aerogel, Spectroscopic infrared ellipsometry, Low refractive index substrate

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1. Introduction

Antenna-coupled microbolometers [1-9] are emerging detectors that possess the potential of providing uncooled, fast response, inherently frequency agile and polarisation sensitive infrared detection all of which will lead to low cost, light weight, fast frame rate infrared imaging systems with high object recognition capabilities. The antenna-coupled microbolometer performance, however, still suffers from low sensitivity when compared to other detectors in its class. The performance of antenna-coupled microbolometers is affected by two main factors: antenna losses and microbolometer losses. Although, antenna losses are due to many factors such as metallic losses, dielectric losses and power coupled to surface waves; however, the power coupled to the underlying substrate was found to be the main factor that limits the reception efficiency of an infrared antenna [10]. Microbolometer losses are mainly due to thermal conduction to the surrounding structures, and the low temperature coefficient of resistance (TCR) of the microbolometer material; materials with high temperature coefficient cannot be impedance matched to the antenna [11]. Substrate side illumination [12], dielectric lenses [13], and Fresnel lenses [14] were attempted to improve the performance of the antenna-coupled microbolometer and overcome the antenna losses. In addition, many attempts were made to reduce the microbolometer losses, such as providing better thermal insulation by air bridge suspension [15], using spin-on nanometre thin films of aerogel [7] on Silicon substrate, and employing microbolometer material having large TCR [16]. Despite all these efforts, the detectivity of an antenna-coupled microbolometer is still about two orders of magnitude less than other detectors in its class. Using a substrate of low dielectric constant and low thermal conductivity would improve the performance of antenna-coupled microbolometer by reducing antenna losses due to power coupling to the substrate meanwhile providing a better thermal insulation to the microbolometer element and therefore improving the microbolometer responsivity. Aerogels are a special class of continuously porous solid materials that have nano-sized pores and particles; they are known by their low dielectric constant in the visible spectrum, in addition to their low thermal conductivity [17]. Thus, they may present an appropriate substrate material for antenna-coupled microbolometers provided they maintain their low dielectric constants at long wave infrared (LWIR) wavelengths. In this paper, we measure the refractive index, *n*, and the extinction coefficient, *k*, of a novel silica aerogel substrate using infrared spectroscopic ellipsometry in the wavelength range from 8 to 14 µm. The substrate is composed of silica aerogel encapsulated in polymer aerogel. The results were analyzed to assess the suitability of the substrate material for infrared antenna-coupled microbolometers.

2. Experiment

The substrate under investigation is silica aerogel substrate; the substrate is composed of silica aerogel encapsulated in polymer aerogel; the silica aerogel substrate was provided by TAASI corporation®. The substrate has a thickness of 1.4 mm; it has a white colour and it is flexible. The substrate has a sheet resistance of 250×10^6 Ω/sq., a density of approximately 0.105 g/cm^3 and a thermal conductivity of approximately 13 mW/m·K, estimated from [18]. The thermal conductivity is lower than the thermal conductivity of air, 26 mW/m·K, providing superior thermal insulation for microbolometers than the complicated air bridge process. A scanning electron micrograph for the surface of the silica aerogel substrate under investigation is shown in Fig. 1. The micrograph reveals the porous structure of the silica aerogel surface. Micro and nano-sized pores are observed unevenly distributed across the sample surface with sizes ranging from approximately 10 μm to 50 nm.

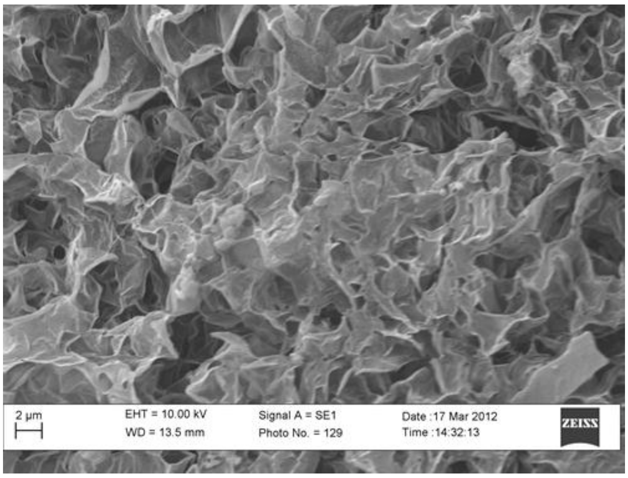

Fig. 1. A Scanning electron micrograph for the silica aerogel substrate surface.

The infrared optical constants for the silica aerogel substrate were measured by reflective infrared spectroscopic ellipsometry using SENDIRA infrared ellipsometer. The setup is shown in Fig. 2. The measurement wavelength ranges from 8 to 14 μm. A Fourier Transform Infrared (FTIR) spectrometer is used as the source for infrared radiation. The infrared radiation is linearly polarized using a broadband polarizer and then made incident on the silica aerogel sample at an angle of 70 degrees from the normal to the sample surface. Part of the infrared radiation incident on the sample surface is reflected from the sample at the same angle and received by a Deuterated TriGlycine Sulfate (DTGS) that is preceded by a compensating analyzer. Using this method, psi (Ψ) and delta (Δ) ellipsometric parameters were recorded at different wavelengths where Ψ represents the ratio between the amplitudes of the parallel and perpendicular components of the reflected wave, and Δ represents the phase shift between them due to the reflection from the substrate [19]. In this particular experiment, the wavenumber resolution was set to 8 cm^{-1} and 1000 intensity scans (i.e. 1000 FTIR mirror movements per analyzer step) were taken at 8 analyzer steps. The recorded Ψ and Δ spectra were then fit to the general ellipsometry equation $\rho = \tan\Psi \cdot e^{i\Delta}$ using a Drude Lorentz oscillator model where two oscillators were used to fit the data. The fit data was then used to obtain the complex refractive index $\tilde{n}$ of the substrate where $\tilde{n} = n + ik$ [20].

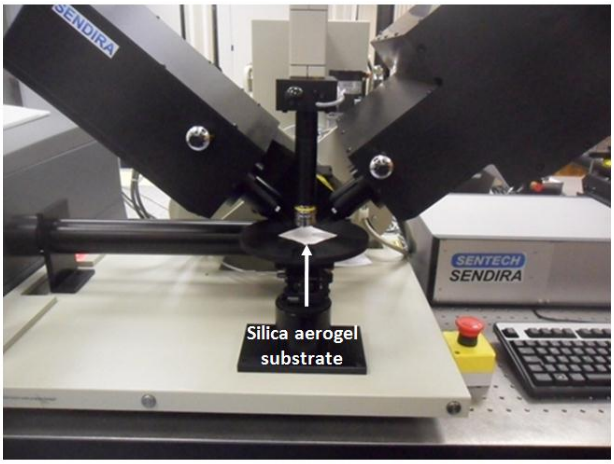

Fig. 2. Photograph for the spectroscopic ellipsometry setup that was used for measuring the infrared optical constants of silica aerogel substrate.

3. Results and discussion

The refractive index and the extinction coefficient of silica aerogel substrate are plotted in Figs. 3 and 4 for the wavelength range of 8 to 14 μm. The refractive index varies slowly from approximately 1.09 to 1.01 and the extinction coefficient shows a variation from approximately 0.0096 to 0.0104.

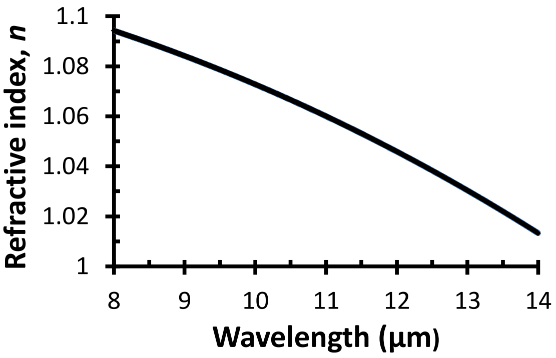

Fig. 3. Measured refractive index, n, versus wavelength plot for silica aerogel substrate.

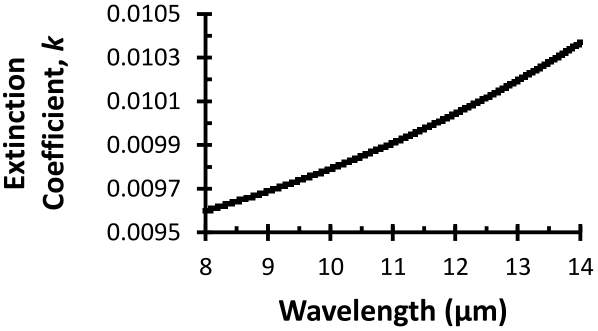

Fig. 4. Measured extinction coefficient, k, versus wavelength plot for silica aerogel substrate.

The measurements confirm the expected low refractive index for silica aerogel which promises an improvement in antenna performance due to minimization of power coupling to the substrate. In the case of a dipole antenna on silicon substrate, the dipole antenna is expected to receive only $\varepsilon_{air}^{3/2}$ / $\varepsilon_{Si}^{3/2}$ or (n_{air}^3 / n_{Si}^3) of the power incident on it [21], while in the case of a dipole antenna on this work's investigated silica aerogel underlying substrate, the same antenna will receive approximately 35 times higher power. Moreover, the measured extinction coefficient of aerogel is lower than the extinction coefficients of SiO_2 and Si_3N_4 films, which are the typical films underlying infrared antenna-coupled microbolometers; hence, no degradation of performance in the form of substrate heating is expected from an underlying silica aerogel substrate when compared to currently utilized technologies. However, this expected performance improvement will be on the expense of detector speed due to the low thermal conductivity of the aerogel substrate; besides, the detector is expected to have higher 1/*f* noise as a result of the roughness of the surface of the silica aerogel substrate.

4. Conclusion

An ellipsometric measurement was carried out to assess the effectiveness of using a novel silica aerogel substrate for antenna-coupled microbolometer LWIR detectors. The results show a very low refractive index, from 1.09 to 1.01, in the wavelength range from 8 - 14 µm which assures much lower antenna losses and thus higher antenna radiation efficiencies. Experimental work is to be initiated for fabricating microbolometers on bulk silica aerogel substrates; difficulties are expected when conventional photolithography will be applied due to the flexible nature, the porosity and the roughness of the aerogel substrate. A thin insulator buffer layer may be deposited on the silica aerogel substrate surface in order to provide a smoother surface for fabricating the antenna-coupled microbolometers. Metallization through stencil masks may also be considered as an alternative to conventional photolithography. Fabrication difficulties are thus comparable to the complex fabrication processes that are currently employed in fabricating the microbolometers on air bridge suspended silicon nitride membranes.

Acknowledgments

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