

Equivalent Emissivity of Poly-Si, SiO₂, and SiN_x for Accurate Heated-Membrane Optical Radiator Design

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Summary:

The temperature-dependent spectral emissivity for poly-Si, SiO₂ and SiN_x of different composition have been extracted from wideband data on the index of refraction available in literature and used to obtain the temperature-dependent equivalent emissivity of these materials. The constraints of the Kirchhoff law of optics are not necessarily satisfied for these materials in combination with the thickness typically used in silicon MEMS devices, which is taken into consideration when applying the data obtained in realistic multi-layered structures.

Keywords: heated-membrane, MEMS optical data, emissivity, optical database, Kirchhoff

Background, Motivation and Objective

The Kirchhoff law of optics states that the power radiated by an object in thermal equilibrium must be equal to the power absorbed, which implies that the spectral emissivity of a material can be expressed in terms of its spectral absorbance. Full emissivity, ϵ^∞ , (which is actually the value described in literature and described by $\epsilon^\infty = (1 - R)$, with R the reflectance can develop only if the layer (or stack of layers) of which the membrane is composed is thick enough to ensure that the radiation is fully absorbed (absorbance $A = 1 - \exp(-\alpha \times t) \sim 1$, with α the absorption coefficient of the material and t the membrane/layer thickness).

This condition is not necessarily satisfied for the silicon-compatible materials used in MEMS microheater design. This applies especially to SiO₂ and SiN_x. Data on the temperature dependence of the emissivity of a material, $\epsilon(T)$, is scarce and often a temperature independent value is taken, which limits the accuracy of the simulation. This study aims to obtain accurate values of the spectral emissivity of these materials for realistic layer thicknesses and over the temperature range between 0-800 °C.

Description of the Approach

Literature data on the wavelength dependent complex index of refraction, $n^* = n - jk$, of polysilicon, SiO₂, N-rich SiN_x and Si-rich SiN_x, as available in literature, is used to build a database. For polysilicon, special emphasis is put on free-carrier absorption and the description

using a parameterized model was found sufficiently accurate [1-5]. For SiO₂ and SiN_x, modeling based on Brendel oscillator parameters, which is often used for modeling the complex index of refraction of a dielectric material, was found sufficiently accurate [6]. Subsequently, the data was used in matrix calculation of reflectance, transmittance and absorbance using optical admittances [7].

Results

The equivalent emissivity, ϵ_{eq} , is defined as the wideband emissivity applied to a black radiator that would result in the same radiance as the layer and material considered.

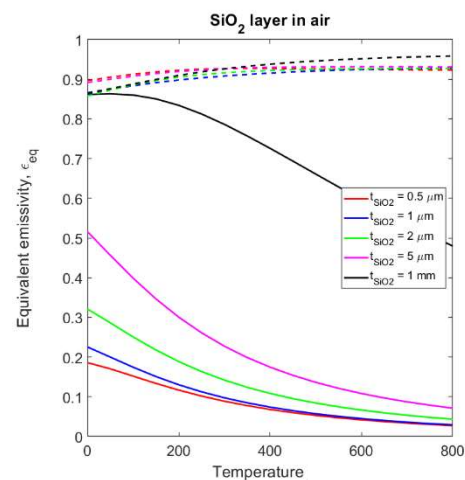


Fig. 1. Equivalent emissivity for an SiO₂ layer in air at temperatures in the range 0 – 800 °C.

The equivalent emissivity of SiO₂ layer with a thickness in the range 0.5-5 μm and suspended

in air is shown in Fig. 1. The emissivity for a macroscopic layer is included for comparison. The Kirchhof constraint is disregarded in the dashed lines. Comparison between the dashed and solid lines reveals that full absorption is not reached in a typical MEMS device.

Although the Si-rich SiN_x is often preferred in the design of a suspended MEMS membrane, because of its tensile stress to keep the surface taut, the optical losses are significantly higher as compared to the N-rich SiN_x . Therefore, the equivalent emissivity, ϵ_{eq} , of an N-rich SiN_x layer deposited on a standard silicon substrate is presented in Fig. 2.

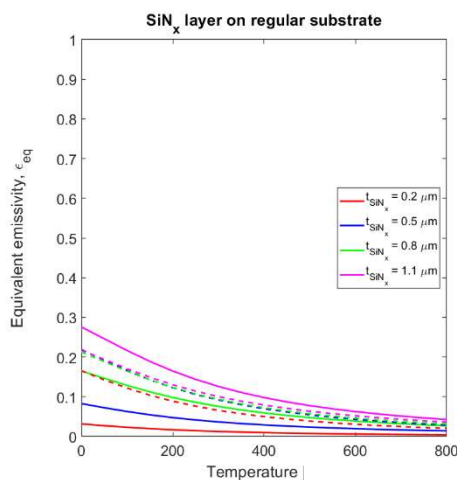


Fig. 2. Equivalent emissivity for a N-rich SiN_x layer on a Si substrate in the temperature range 0–800 °C.

As the membrane is typically suspended from the Si substrate, a realistic simulation of the membrane emissivity should also include such a structure (see Fig. 3).

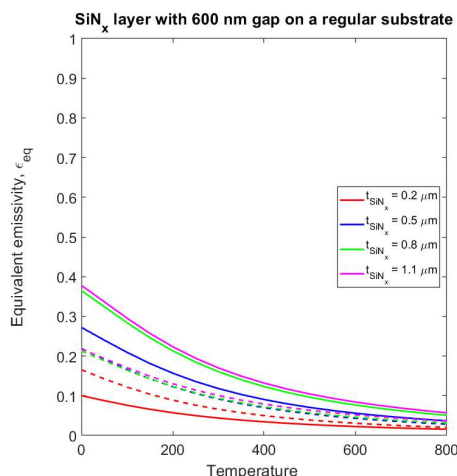


Fig. 3. Equivalent emissivity for a suspended N-rich SiN_x layer in the temperature range 0–800 °C.

Finally, a realistic structure is typically composed of a multi-layer membrane. The results for a poly/ SiN_x membrane are shown in Fig. 4 in

comparison to the poly-Si layer of the same thickness in air (dashed lines).

The approach is suitable for the calculation of the equivalent emissivity of more complex membranes that are fabricated using the set of conventional silicon-compatible materials. Testing, by applying this approach to the results for measurement results of heaters presented in literature shows good agreement.

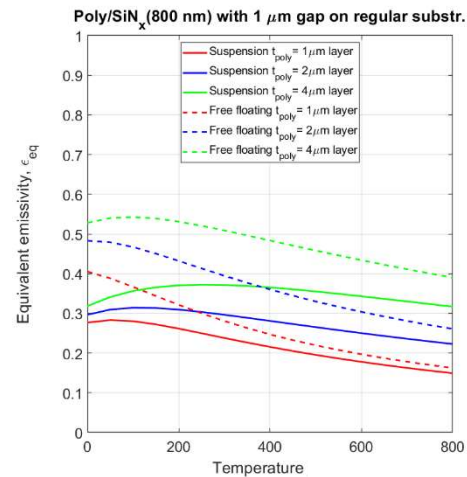


Fig. 4. Equivalent emissivity for a suspended poly-Si/ SiN_x multilayer in the range 0–800 °C.

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