QUASI-OPTICAL BLACKBODY RADIATION SOURCES, ATTENUATORS AND LOADS

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Samples of quasi-optical blackbody radiation sources in the form of a thin resistive film on a dielectric substrate have been developed, manufactured and studied. The emissivity factor of the samples was measured at normal incidence on the quasi-optical tract. The samples give a fairly uniform absorption and radiation, but the emissivity factor is small compared to the same indicator for industrial absorbers in the form of complex three-dimensional structures. However, the use of an integrating cavity makes it possible to almost double the emissivity of the resistive film.

Keywords—blackbody, thin films, quasi-optical radiation sources, emissivity factor

I. INTRODUCTION

Temperature-controlled absorbers are used as a reference source of blackbody radiation for calibration of various quasi-optical microwave devices. The simplest such absorber is a thin metal film on a dielectric substrate. We performed numerical modeling of absorption for films of different resistances on different substrates and determined their optimal parameters. The manufactured samples emissivity and reflectivity were measured in the frequency range of 75-500 GHz. The emissivity factor (blackness coefficient) of simple planar absorbers does not exceed 0.5, but can be increased to 0.95 when placing inside the integrating cavity (sphere).

II. THEORETICAL ASSESSMENT

Industrially produced blackbody absorbers (emitters) are a structure in the form of a plurality of semiconductor cones (Fig. 1.) coated with a special blackening [1]. Such an absorber can be extremely effective, for example, specially grown carbon nanotube bristles [2] can have an absorption coefficient of up to 99.96%.

Fig. 1. Photo of the structure of industrial absorber cones

However, such three-dimensional structures do not work at cryogenic temperatures and do not allow to quickly change the radiation temperature. The absorber, which is a thin metal film on a dielectric substrate, is devoid of these disadvantages, but it must be taken into account that the absorption coefficient does not exceed 0.5.

It is clear that the resistance per square of the resistive film should be comparable to the wave resistance of the free space $Z_0 = 377\Omega$. Usually, the wavelength and the skin depth are much larger than the thickness of the film, in our case, the thickness of the manufactured films does not exceed 1.5 micrometers, and the wavelength of the incident radiation is 0.6-4 mm.

In the case of two different dielectrics from different sides of the absorber film [3], the absorption coefficient $A = 4 Z_0\sigma/(n_1+n_2 + Z_0\sigma)^2$, in this formula, n_1 and n_2 denote the refractive coefficients of dielectrics, σ – electrical conductance. For vacuum on both sides $A = 4 Z_0\sigma/(2 + Z_0\sigma)^2$. In this case, the maximum value does not exceed 0.5 with a resistance per square $R_\square = Z_0/2 = 188\ \Omega/\square$. For an arbitrary

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value of the refractive index of the second dielectric, $A = 4Z_0\sigma/(1 + n_2 + Z_0\sigma)^2$.

The maximum $A_{max} = 1/(n_2 + 1)$ is reached for resistance $R_\square = Z_0/(n_2 + 1)$.

For thick substrates made of silicon, quartz and sapphire, $R_\square$ and A_{max} have the following values:
$R_{\square\,Si} = 84\ \Omega/\square$ and $A_{max\,Si} = 0.22$
$R_{\square\,SiO2} = 120\ \Omega/\square$ and $A_{max\,SiO2} = 0.32$
$R_{\square\,Al2O3} = 100\ \Omega/\square$ and $A_{max\,Al2O3} = 0.26$.

CST Studio Suite software was used to simulate the absorption coefficient of a thin film. A schematic representation of the project is shown in Figure 2. A thin film on a dielectric substrate of the selected material is placed inside the waveguide between two ports for generating and receiving a signal.

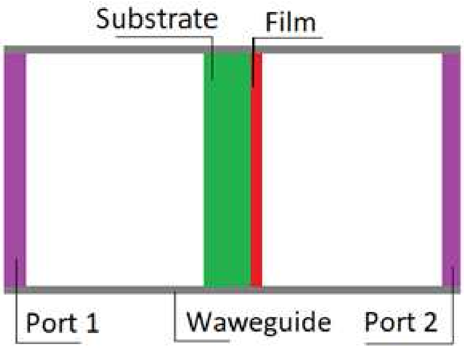

Fig. 2. Schematic representation of the cross section of the project [3]

In the case of placing the film on a substrate with a thickness comparable to the wavelength, the spectral characteristic of absorption and radiation becomes periodic. as in the Fabry - Perot interferometer (Fig. 3)

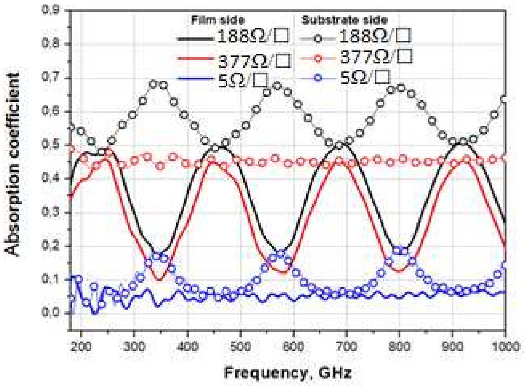

Fig. 3. Results of calculations for a NiCr film on a 340 µm thick Al_2O_3 substrate.

Significantly increase of the degree of blackness of the absorber is reached by using of an integrating cavity, see Fig.4.
Radiation is repeatedly reflected from the walls of the integrating cavity and repeatedly hits the film.

Fig. 4. Photo of the integrating cavity.

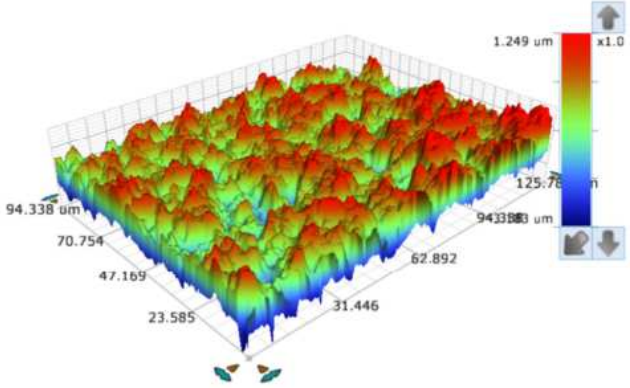

Fig. 5. An image of the film on an unpolished substrate taken on an optical profilometer..

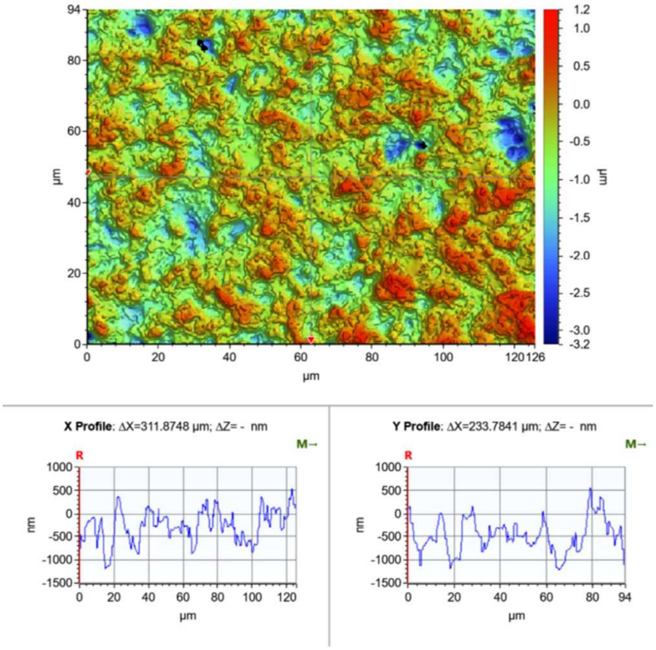

Fig. 6. An image of the film on an unpolished substrate taken on an optical profilometer..

III. EXPERIMENTAL

All samples were made by thermal evaporation, during manufacture the same experimental conditions were maintained (as far as possible): time and power of pre-evaporation, deposition pressure, film evaporation speed. The characteristics of the samples and measurement data are presented in the table 1.

Table 1. Table with experimental data.

Sample number	**1**	**2**	**3**	**4**	**5**	**6**
Substrate material	**glass**	**glass**	**glass**	**glass**	**crystalline SiO_2**	**Al_2O_3**
substrate thickness (μm)	100	100	100	100	200	400
film material	NiCr	NiCr	NiCr	NiCr	NiCr	NiCr
R/□ (Ω /□)	115	99	73	43	113	118
the transmission coefficient of on the film side (450 GHz)	0,15	0,12	0,06	0,036	0,06	0,09
the transmission coefficient of on the substrate side (450 GHz)					0,04	0,11
the transmission coefficient of on the film side (95 GHz)	0,12	0,075	0,045	0,023	0,05	0,07
the transmission coefficient of on the substrate side (95 GHz)					0,03	0,09
reflection coefficient of on the film side (95 GHz)	0,44	0,56	0,63	0,78	0,64	0,54
reflection coefficient of on the substrate side (95 GHz)					0,84	0,09
degree of blackness on the film side (95 GHz)	0,44	0,365	0,325	0,197	0,31	0,39
degree of blackness on the substrate side (95 GHz)					0,13	0,82

A cover glass (amorphous SiO2) with a thickness of 100 µm, quartz and sapphire polished substrates (films No. 5 and No. 6) were used as substrates.

The measurements were carried out in the quasi-optical 4-lens beamguide with a normal incidence to film surface or substrate back side.

For films No. 1 and No. 2 (for example, these films are selected because they are on the same substrates and have similar resistance) at a frequency of 95 GHz, the reflection coefficients were 0.44 and 0.56, the transmission coefficients were 0.12 and 0.075, i.e. the emissivity was 0.44 and 0.365, respectively. For the same films at a frequency of 450 GHz, the transmission coefficient was 0.15 and 0.12, respectively, i.e., within the error limits, such loads give fairly uniform absorption and radiation.

A similar pattern is observed for other samples. Separately, it is worth paying attention to film No. 6. Since the electrical thickness of the substrate is approximately equal to half the wavelength of radiation at a frequency of 95 GHz, the absorption coefficient is significantly higher than that of other films. Taking into account the measurement error, the data obtained are consistent with the data of the theoretical assessment.

A 200 Ω/□ film was made on an unpolished silicon substrate (Fig. 5, Fig. 6) with a roughness of more than 1.5 µm. In the integrating cavity, the emissivity was 0.85 at a frequency of 75 GHz.

IV. CONCLUSIONS

Several samples of blackbody radiation sources in the form of NiCr films of various resistance on dielectric substrates have been developed and fabricated. The samples give a fairly uniform absorption and radiation.

It should be noted that blackbody radiation sources in the form of NiCr films can be used in a wide temperature range, since the electrical resistance of NiCr weakly depends on temperature.

However, even with a normal incidence on the quasi-optical path, the degree of emissivity does not exceed 0.5, while the use of an integrating cavity allows you to significantly increase the degree of blackness of the entire assembly (integrating cavity + absorber).

When using an integrating cavity, the values of the blackness of the simplest absorber approach those of a complex three-dimensional structure, but simply a resistive film on a dielectric substrate works significantly less efficiently.

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