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Effect of roughness on the emissivity of the precious metals silver, gold, palladium, platinum, rhodium, and iridium

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Abstract. The effect of roughness on the directional spectral emissivity as well as the directional and hemispherical total emissivities was systematically studied for the precious metals silver, gold, palladium, platinum, rhodium, and iridium in order to avoid or minimise the effect of oxidation and other chemical reactions. The microtopography of these surfaces, which were mechanically treated by rolling, turning, grinding, lapping, and polishing, and subjected to an appropriate thermal treatment to remove crystal structure defects caused by roughening, was characterised by roughness measurements yielding roughness profiles and their statistical characteristics such as roughness height, roughness transfer length, and average slope of surface elements. The emissivities were measured by radiometric techniques in the wavelength range 2.5 μm to 51 μm and in the angular range 0° to 75° at a temperature of 150 °C. The results of the emissivity and roughness measurements are discussed within the scope of the existing theories for the emissivity of rough surfaces. It was found that roughnesses with heights smaller than a fraction 0.01 of the wavelength can still affect the radiative properties of the surface. However, the emissivity does not monotonically increase with the roughness height but rather correlates with the slope of parts of the surface profile. For the same metal with different surface finish, the directional total emissivity was observed to vary by at most a factor of 20. These changes are much larger than those caused by structural defects due to roughening and should be attributed to the surface topography.

1 Introduction

The roughness is one of the surface imperfections of solids that affect their thermal radiation properties. Frequently as a result of mechanical treatment of surfaces, particularly in the case of materials with low emissivity like metals, their emissivity can change significantly. There are a lot of works in which the emissivity and reflectivity of surfaces are studied in dependence on roughness parameters and, first of all, on a characteristic roughness height (Siegel and Howell 1982). Qualitatively, three borderline cases can be distinguished in which the characteristic roughness height, usually the root-mean-square (rms) roughness (R_q), is much greater than, comparable with, or much lower than the wavelength of radiation (λ). In the first case, the laws of geometrical optics are applicable to describe the interaction of radiation with the surface, and multiple reflections on walls of surface hollows lead to the emissivity rising with increasing roughness height. In the second case, diffraction models are applied to describe the radiative properties of the surface with the result that only the directional emissivity is a function of roughness, whereas the hemispherical emissivity is no longer dependent on it. In the third borderline case, the surface can be considered to be optically smooth with the radiative properties approaching those of the perfectly smooth surface.

However, a quantitative comparison of emissivity results furnished by theoretical models with those experimentally obtained for rough materials has shown that the description of the surface topography solely in terms of rms roughness height is insufficient to predict the emissivity of the rough surface satisfactorily. Because surfaces of engineering materials after common finishing operations are characterised by a random topography, in models developed to predict their radiative properties, a statistical description of roughness is usually used which, besides the rms roughness, includes such characteristic parameters as the roughness height distribution, the autocorrelation distance (S_m), and/or rms slope (φ) of surface elements. Some of the restrictions for the relationship R_q/λ required in earlier works based on the diffraction theory (Davies 1954; Beckmann and Spizzichino 1963; Houchens and Hering 1967) were eliminated by Porteus (1963) and shadowing effects at observation directions nearly tangent to the surface taken into account (Smith 1967; Birkebak and Abdulkadir 1976).

Surface structures with large R_q/λ were studied by Agababov (1970), Black (1973), Demont et al (1982), and others. For a regular pattern, fairly good agreement between experimental and theoretical results could be observed. However, when irregular surface structures were investigated as they appear, for example, after sand-blasting or ball-blasting, even under the condition $R_q/\lambda \gg 1$, rather poor agreement between theory and experiment was found. This experience can be qualitatively explained by the results of the recent theoretical works (Dimenna and Buckies 1994; Tsang et al 1994; Yang and Buckies 1995; Makino 1997; Makino et al 1998) in which rigorous electromagnetic scattering solutions for rough surfaces with different length scales were obtained by advanced computer techniques. There it was concluded that for a surface profile consisting of several substructures with different roughness scales, the one with the steepest slope of the surface flanks is decisive for the radiative properties of the surface.

An experimental verification of theoretical models is complicated because it is practically impossible to create surfaces with different roughness parameters but with all other properties remaining the same. Any mechanical surface treatment not only usually leads to a new surface topography but also causes damage of the material structure beneath the surface, contamination, chemical reactions and, first of all, oxidation of the surface (DeWitt 1965). All these effects also modify the radiative properties of the material so that an observed change in emissivity after the mechanical treatment cannot be attributed only to the change of roughness. As was concluded by Bennett (1965), only the structural damage and surface films and not the roughness itself are responsible for experimentally observed changes in the emissivity when the rms roughness is comparable to or smaller than the wavelength.

In the present work, the precious metals gold, silver, palladium, platinum, iridium, and rhodium were chosen as subjects to avoid or minimise the effect of oxidation and other chemical reactions. After roughening, the samples were subjected to an appropriate thermal treatment to remove crystal structure defects caused by roughening. The intention was to determine the correlation between the roughness parameters of the surfaces and their emissivity. When the roughness of the surfaces was then reduced, the limiting roughness had to be found below which the emissivity of the material was no longer sensitive to roughness so that the surfaces could be considered optically smooth. In this way, 'true' values for the spectral and total emissivity of the six metals had to be determined.

2 Measurement of total and spectral emissivity

The principle of determination of the total directional and spectral directional emissivity consisted in the comparison of the radiance of a sample with that of a blackbody. Two techniques were applied; they are described in detail by Lohrengel (1987) and Lohrengel et al (1993) and are briefly presented below.

2.1 *Total directional and hemispherical emissivity*

A sample, blackbody, and a radiometer are placed in a chamber evacuated to 3×10^{-5} Pa. The sample is mounted on a sample holder made of copper with a thin grease film between them to ensure good thermal contact. It is surrounded by a black enclosure provided with an orifice for sample observation. The radiometer uses a Kipp & Zonen thermopile (Moll type) with a sensitivity of $0.6\,\mu\mathrm{V}\,\mu\mathrm{W}^{-1}$ as a total radiation detector. It can alternatively be positioned in front of the enclosure or blackbody opening to measure the heat radiation fluxes from the sample surface and the blackbody. The latter is made of copper in the form of a cavity, and its walls are V-grooved and blackened with a Nextel Velvet 811-21 coating. The apparent emissivity of the blackbody is estimated to lie between 0.9990 and 0.9999. The temperatures of sample holder, blackbody, radiometer, and enclosure are controlled by thermostated liquids and measured by platinum resistance thermometers (PRT) calibrated to ITS-90. The temperature range of the measurements is $-60\,^{\circ}\mathrm{C}$ to $250\,^{\circ}\mathrm{C}$. The sample holder can be rotated to enable ε_θ to be measured within the angular range $\theta = 0^{\circ}$ to 75°. The ε_θ values measured at several θ are fitted by Fresnel's equation with the optical constants as parameters which, multiplied by $2\sin(\theta)\cos(\theta)$ and integrated from $\theta = 0^{\circ}$ to 90°, allow the total hemispherical emissivity ($\varepsilon_{\underline{\cap}}$) to be found (Janßen and Lohrengel 1991). The temperature of the sample surface is determined indirectly by equalisation of the heat flux from the sample holder to the sample surface, which is calculated from the dimensions and the thermal conductivities of the sample and the contact grease film, and the radiative heat loss from the surface. As the latter requires that $\varepsilon_{\underline{\cap}}$ is known, the evaluation is obtained by an iterative approach, including alternating calculation of the surface temperature and the total hemispherical emissivity until convergence is achieved.

2.2 *Spectral directional emissivity*

The spectral directional emissivity ($\varepsilon_{\lambda\theta}$) in the range $\lambda = (2.5-51)\,\mu\mathrm{m}$ is determined with a modified Fourier transform infrared (FTIR) Nicolet 5DXB spectrometer with a deuterated triglycine sulfate (DTGS) detector for measurement of the radiative fluxes emitted by a sample and a blackbody. The spectral resolution of the instrument in wavenumbers was chosen to be $8\ \mathrm{cm}^{-1}$. The measurement is made in air and, to minimise the effect of absorbing bands of H_2O and CO_2, dry air is continuously blown through the spectrometer optical bench enclosure. The sample of known thermal conductivity is mounted on an electrically heated sample holder and surrounded by a thermostated black enclosure. The blackbody similar to that for ε_θ measurements is heated by a thermostated fluid. The temperatures of sample holder, enclosure, blackbody, and DTGS detector are measured by platinum resistance thermometer (PRT) calibrated to ITS-90. The temperature range of $\varepsilon_{\lambda\theta}$ measurements is $50\,^{\circ}\mathrm{C}$ to $600\,^{\circ}\mathrm{C}$, whereas the maximum temperature of the blackbody is limited to $250\,^{\circ}\mathrm{C}$. Because 80% to 99% of the thermal radiation energy is emitted in the spectral range covered, integrating $\varepsilon_{\lambda\theta}$ over the wavelength and then over the angle allows ε_θ and $\varepsilon_{\underline{\cap}}$ to be determined. The latter is required for determining the sample surface temperature which, similar to that in the total emissivity measurement, is calculated by the energy conservation principle for the heat flux in the sample and the energy loss at the surface. In addition to the irradiated energy, a convective energy loss is taken into account by a solution for the isothermal vertical wall given by Incropera and DeWitt (1981). Again, as the sample surface temperature and $\varepsilon_{\underline{\cap}}$ are interdependent, they are found iteratively.

3 Samples

The samples were made of compact molten gold, silver, palladium, platinum, iridium, and rhodium with the following purity: gold, 99.99%; silver, 99.97%; palladium, 99.95%; platinum, rhodium, and iridium, 99.9%. They had the form of a disk 90 mm in diameter and $(2.7-3.4)$ mm in thickness. In their initial state, the surfaces of gold, silver, and platinum were treated by rolling and the surfaces of palladium, iridium, and rhodium by turning. Surfaces with different roughness characteristics were then created by unidirectional grinding with a grindstone and lapping with Al_2O_3 compounds of grit sizes $12\,\mu\mathrm{m}$ and $3\,\mu\mathrm{m}$. Final surfaces with smallest roughnesses were obtained by polishing with Al_2O_3

and diamond compounds and in the case of particularly soft gold and silver, alternatively with the aid of a CNC/interferometer-controlled turning machine equipped with a diamond cutter. For roughness measurements, a contact stylus instrument, Mahr Perthometer S8P (Mahr GmbH, Göttingen, Germany), equipped with a ruby stylus of 2 μm radius and 90° taper angle was used. The stylus force was equal to 0.6 mN. The tracing lengths (l) were 0.56 mm in the polished and 5.6 mm in all other states of the surface. Roughness profiles, $y(x)$, were recorded in the middle of the sample in four directions separated by 45° and additionally in one direction at eight places equidistantly distributed around the sample centre at a distance of 35 mm. The autocorrelation distance was defined as a distance S_m at which the autocorrelation function $\mathrm{ACF}(S_\mathrm{m})$, given by

$$\mathrm{ACF}(S_\mathrm{m}) = S_\mathrm{m}^{-1} \int_0^{S_\mathrm{m}} y(x) y(x + S_\mathrm{m})\,\mathrm{d}x \ ,$$

tends to zero. The rms slope, φ, was calculated according to:

$$\tan(\varphi) = \left[l^{-1} \int_0^l \left(\frac{\mathrm{d}y}{\mathrm{d}x} \right)^2 \mathrm{d}x \right]^{1/2} \ .$$

Thus, for each surface, twelve values were obtained for each of the roughness parameters and, therefore, the mean, minimum, and maximum values were used to characterise the surface. In order to distinguish the effects of roughness and structural damage induced by the mechanical treatment of surfaces, after roughening, the samples were annealed in the vacuum at temperatures of 300 °C (silver and gold), 500 °C (palladium), 600 °C (platinum), 650 °C (rhodium), and 800 °C (iridium), which correspond to the recovery temperatures for these metals. The emissivity was measured before and after annealing and, assuming that structural defects are removed by the thermal treatment, the effect of structural damage could be quantified by the emissivity change observed. The influence of annealing was mainly studied when mechanical processing of the samples led to a lower R_q but, against expectations, to a higher emissivity. All emissivity measurements were performed at the temperature of 150 °C. ε_θ was determined for angles $\theta = 0°$, 15°, 30°, 45°, 60°, 69°, 72°, and 75° and $\varepsilon_{\lambda\theta}$ for $\theta = 5°$, 15°, 30°, 40°, 45°, 50°, 55°, and 60°.

4 Results and discussion

The mean values of the roughness parameters of the differently prepared sample surfaces, their normal and hemispherical total emissivities obtained as averages from ε_θ and $\varepsilon_{\lambda\theta}$ measurements are given in table 1. With the exception of palladium treated by turning, all samples had roughness heights smaller than 1 μm which thus were significantly smaller than the wavelength of the blackbody's emissive spectrum maximum (λ_max), which was 6.8 μm. According to the diffraction theories applicable to surfaces with optical roughnesses $R_\mathrm{q}/\lambda_\mathrm{max} \ll 1$, the hemispherical spectral emissivity should no longer be dependent on roughness. However, the experimental results show the total emissivity to be very sensitive to the state of the surfaces in this optical roughness range. Particularly the results of the palladium sample, which was polished twice, once less and once more carefully, demonstrate that the optical roughness even below 0.004 can still considerably modify the emissivity.

Annealing of the samples,which was intended to eliminate structural defects caused by the roughening, in all but one case reduced the normal and hemispherical emissivities by no more than 0.018. As most emissivity variations observed after roughening of the surfaces are greater than the effect of annealing, evidently it is rather the surface topography and not the structural defects which give rise to the emissivity changes. In the case of silver lapped with grit of 3 μm, annealing slightly increased the emissivity. However, this increase is probably caused by chemical contamination of the surface. There was a period of time of more than one year between the measurements on the non-annealed and the

Table 1. Arithmetic and rms roughness heights (R_a and R_q), autocorrelation distance (S_m), rms slope of surface elements (φ), normal and hemispherical emissivities (ε_n and $\varepsilon_{\underline{\cap}}$) as averages of those determined from ε_θ and $\varepsilon_{\lambda\theta}$ measurements. In brackets, the emissivities of annealed samples are given.

	Preparation	R_a/μm	R_q/μm	S_m/μm	φ/deg	ε_n	$\varepsilon_{\underline{\cap}}$
Pt	rolled	0.13	0.18	76	0.82	0.050	0.064
	ground	0.43	0.57	36.94	8.1	0.064	0.075
	lapped, grit 12 μm	0.52	0.66	31	13	0.210 (0.193)	0.210 (0.209)
	polished	0.006	0.009		0.97	0.037 (0.037)	0.051 (0.046)
Au	rolled	0.082	0.11	120	0.67	0.027	0.035
	ground	0.36	0.47	35	6.8	0.019	0.024
	lapped, grit 12 μm	0.61	0.77	33	15	0.113 (0.099)	0.112 (0.109)
	turned by diamond	0.007	0.010		0.66	0.015	0.020
	polished	0.021	0.029		1.5	0.018 (0.012)	0.021 (0.017)
Ir	turned	0.55	0.76	400	1.7	0.040	0.056
	ground	0.12	0.17	79	1.1	0.042	0.053
	lapped, grit 12 μm	0.20	0.25	21	7.6	0.121	0.139
	polished	0.001	0.002		0.2	0.033 (0.026)	0.042 (0.034)
Rh	turned	0.53	0.69	450	2.8	0.056	0.070
	ground	0.11	0.14	42	2.3	0.033	0.043
	lapped, grit 12 μm	0.12	0.15	17	5.3	0.225 (0.207)	0.245 (0.228)
	polished	0.004	0.007		0.71	0.029	0.039
Pd	turned	2.7	3.4	74	17	0.229	0.237
	lapped, grit 3 μm	0.23	0.29	22	8.1	0.263 (0.259)	0.273 (0.268)
	polished 1	0.018	0.028		3.3	0.102	0.126
	polished 2	0.004	0.005		0.8	0.042	0.054
Ag	rolled	0.15	0.19	74	1.0	0.013	0.016
	ground	0.23	0.30	26	5.8	0.015	0.019
	lapped, grit 12 μm	0.58	0.73	30	15	0.163 (0.145)	0.161 (0.144)
	lapped, grit 3 μm	0.24	0.31	24	8.1	0.195 (0.210)	0.212 (0.212)
	turned by diamond	0.011	0.013		0.87	0.011	0.015

annealed sample and, as silver is known to become black in air with time because of formation of Ag_2S, the chemical contamination might have distorted the results obtained for the annealed sample (all other measurements were performed shortly after surface treatment). In the polished state, the annealing of platinum, gold, and iridium reduced ε_n and $\varepsilon_{\underline{\cap}}$ by 0.008 at most.

For all metals, the lowest emissivities were measured on the smoothest surfaces when these were polished or turned by diamond. The measured emissivities are for palladium greater than, for silver lower than, and for other metals in agreement with values obtained in other works cited by Latyev et al (1974) and Lohrengel (1989): $\varepsilon_n = 0.043-0.052$, 0.02, 0.028, and $0.02-0.05$ for platinum, rhodium, palladium, and silver, respectively; $\varepsilon_{\underline{\cap}} - 0.05-0.125$, $0.021-0.044$, and $0.019-0.053$ for platinum, gold, and silver, respectively. The highest emissivities were obtained for the surfaces treated by lapping, although only in the cases of platinum, gold, and silver did the lapped surfaces have the highest roughnesses. Moreover, in contrast to expectations, the emissivity did not really monotonically depend on the roughness height. An analysis of the roughness parameters of the differently treated surfaces shows that all lapped surfaces are characterised by the smallest autocorrelation distances and, with the exception of the palladium sample, by the steepest slopes of the surface profile sections. Thus, in agreement with the theoretical predictions made by Tsang et al (1994), Dimenna and Buckies (1994), and Yang and

Buckies (1995), the slope of the surface elements is the parameter determining the emissivity of a rough surface.

The directional total emissivities of the six metals subjected to different kinds of mechanical treatment are presented in figures 1 and 2. Circles stand for the values measured with the total emissivity instrument. Crosses indicate the values determined by

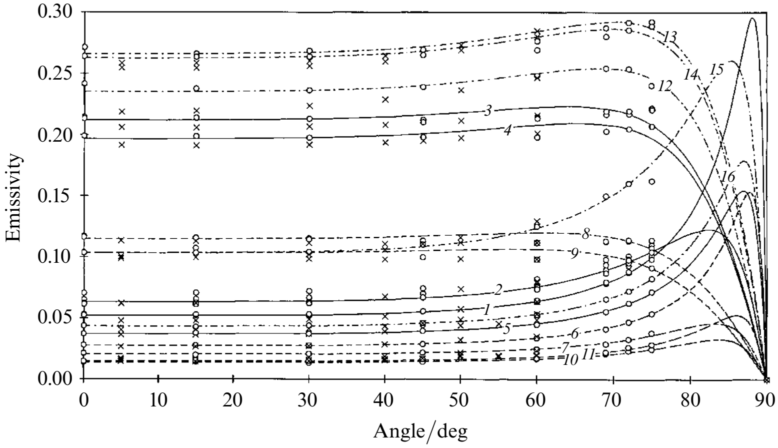

Figure 1. Directional total emissivity of platinum (—, *1–5*), gold (- - -, *6–11*), and palladium (— · — ·, *12–16*) at 150 °C determined from total (○) and spectral (×) measurements for surfaces: *1*, $R_q = 0.18\,\mu$m, rolled; *2*, $R_q = 0.57\,\mu$m, ground, different orientations; *3*, $R_q = 0.66\,\mu$m, lapped with grit of 12 μm; *4*, $R_q = 0.66\,\mu$m, lapped and annealed at 600 °C; *5*, $R_q = 0.009\,\mu$m, polished and annealed at 600 °C; *6*, $R_q = 0.11\,\mu$m, rolled; *7*, $R_q = 0.47\,\mu$m, ground; *8*, $R_q = 0.77\,\mu$m, lapped with grit of 12 μm; *9*, $R_q = 0.77\,\mu$m, lapped and annealed at 300 °C; *10*, $R_q = 0.010\,\mu$m, turned by diamond; *11*, $R_q = 0.029\,\mu$m, polished; *12*, $R_q = 3.4\,\mu$m, turned; *13*, $R_q = 0.29\,\mu$m, lapped with grit of 3 μm; *14*, $R_q = 0.226\,\mu$m, lapped and annealed at 500 °C; *15*, $R_q = 0.028\,\mu$m, polished 1; *16*, $R_q = 0.005\,\mu$m, polished 2.

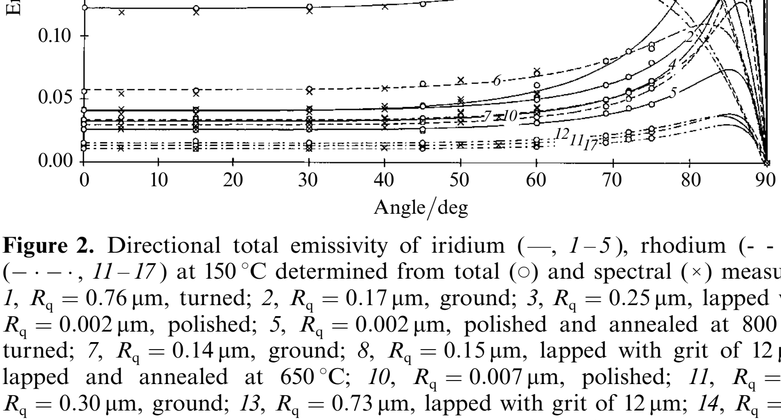

Figure 2. Directional total emissivity of iridium (—, *1–5*), rhodium (- - -, *6–10*), and silver (— · — ·, *11–17*) at 150 °C determined from total (○) and spectral (×) measurements for surfaces: *1*, $R_q = 0.76\,\mu$m, turned; *2*, $R_q = 0.17\,\mu$m, ground; *3*, $R_q = 0.25\,\mu$m, lapped with grit of 12 μm; *4*, $R_q = 0.002\,\mu$m, polished; *5*, $R_q = 0.002\,\mu$m, polished and annealed at 800 °C; *6*, $R_q = 0.69\,\mu$m, turned; *7*, $R_q = 0.14\,\mu$m, ground; *8*, $R_q = 0.15\,\mu$m, lapped with grit of 12 μm; *9*, $R_q = 0.15\,\mu$m, lapped and annealed at 650 °C; *10*, $R_q = 0.007\,\mu$m, polished; *11*, $R_q = 0.19\,\mu$m, rolled; *12*, $R_q = 0.30\,\mu$m, ground; *13*, $R_q = 0.73\,\mu$m, lapped with grit of 12 μm; *14*, $R_q = 0.73\,\mu$m, lapped and annealed at 300 °C; *15*, $R_q = 0.31\,\mu$m, lapped with grit of 3 μm; *16*, $R_q = 0.31\,\mu$m, lapped and annealed at 300 °C; *17*, $R_q = 0.013\,\mu$m, turned by diamond.

integrating the spectral emissivities. Curves are described by Fresnel's equation fitted to the respective data sets. The general tendency is that smoother surfaces radiate as typical perfect conductors with a strong increase in emissivity with increasing angles, whereas rough surfaces with their almost constant directional emissivities in a wide angular range behave rather as diffuse radiators.

The effect of regular grooves for the surfaces after unidirectional grinding on the azimuthal distribution of the emitted radiation was studied on the ground platinum sample. Six measurements performed on the sample viewing it under azimuth angles of 0°, 45°, and 90° to the groove direction did not, however, show any systematic dependence and only random scatter as typical of the measuring instrument used, so all the results can be identified by one curve (*2*).

The normal spectral emissivities of the metals are shown in figures 3 and 4. In the polished state, at $\lambda > 10\,\mu m$, the metals have almost constant emissivities which rise rapidly with decreasing wavelength at $\lambda < 5\,\mu m$. The emissivity of the rough samples depends on the wavelength in the entire spectral interval of the measurements. The differences

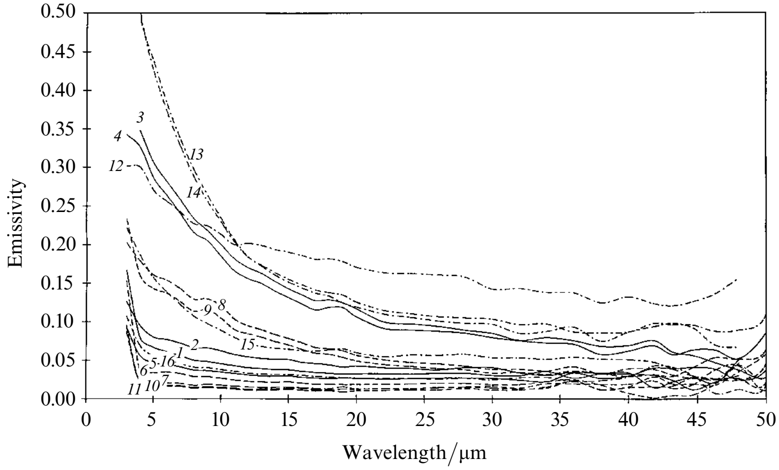

Figure 3. Normal spectral emissivity of platinum (—, *1–5*), gold (- - -, *6–11*), and palladium (— · — ·, *12–16*) at 150 °C. The meaning of the numbers is the same as in figure 1.

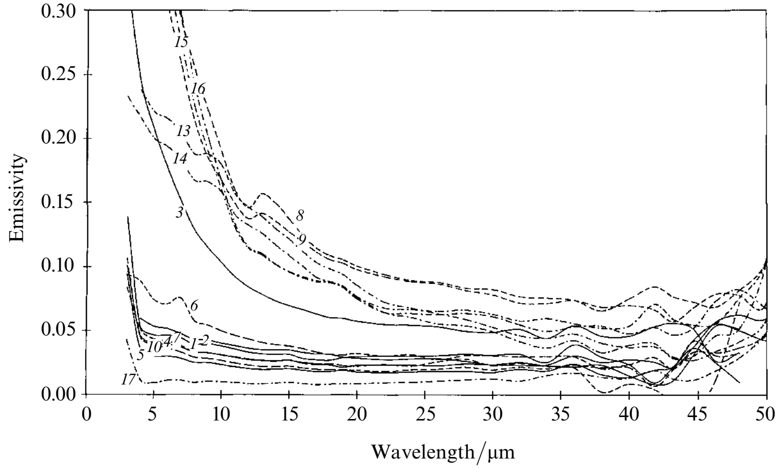

Figure 4. Normal spectral emissivity of iridium (—, *1–5*), rhodium (- - -, *6–10*), and silver (— · — ·, *13–17*) at 150 °C. The meaning of the numbers is the same as in figure 2.

Table 2. Standard uncertainties of measured/estimated quantities, $s(Q)$, and emissivities, $s(\varepsilon)$.

Quantity	ε_θ measurement		$\varepsilon_{\lambda\theta}$ measurement	
	$s(Q)$	$s(\varepsilon_\theta)$	$s(Q)$	$s(\varepsilon_\theta)$
T of sample holder	0.1 K	$1 \times 10^{-3}\varepsilon_\theta$	0.05 K	$5 \times 10^{-4}\varepsilon_{\lambda\theta}$
T of blackbody	0.1 K	$1 \times 10^{-3}\varepsilon_\theta$	0.05 K	$5 \times 10^{-4}\varepsilon_{\lambda\theta}$
T of detector	0.1 K	$5 \times 10^{-5}\varepsilon_\theta$	0.05 K	$3 \times 10^{-5}\varepsilon_{\lambda\theta}$
T of sample surface, additionally	0.04 K	$4 \times 10^{-4}\varepsilon_\theta$	0.3 K	$3 \times 10^{-3}\varepsilon_{\lambda\theta}$
ε of blackbody	$\geqslant 0.999$	$7 \times 10^{-4}\varepsilon_\theta$	$\geqslant 0.999$	$7 \times 10^{-4}\varepsilon_{\lambda\theta}$
Angular adjustment of sample	0.03°	$< 2 \times 10^{-4}$	0.3	$< 1 \times 10^{-3}$
Angle of divergence	2.8°	$< 1 \times 10^{-3}$		
Voltage of thermopile	18 nV	2×10^{-3}		
Non-linearity of spectrometer				$1 \times 10^{-4}\varepsilon_{\lambda\theta}$
Typical reproducibility, type A		$< 5 \times 10^{-3}$	at $\lambda/\mu\text{m} = 2.5-4;\ 45-51$:	1×10^{-1}
			$4-4.5;\ 40-45$:	3×10^{-2}
			$27-40$:	1×10^{-2}
			$4.5-27$:	4×10^{-3}
Combined standard uncertainty of ε		6×10^{-3}	at $\lambda/\mu\text{m} = 4.5-27$:	6×10^{-3}

between the emissivities of the rough and smooth surfaces are a maximum in the region of short wavelengths where the differences of the optical roughnesses are a maximum. A comparison of the emissivities in the long wavelength range demonstrates again that the emissivity of highly reflecting materials can still be sensitive to optical roughnesses even if they are smaller than 0.01. For all metals, annealing and, therefore, the surface structure defects do not change the emissivity by more than 0.02 at any wavelength of the measurements.

A survey of main uncertainty sources with their contributions to the uncertainty of the reported directional total and spectral emissivities is given in table 2. The total directional emissivities measured directly and those calculated by integrating the spectral emissivities agreed in all cases within the uncertainties claimed. The combined standard uncertainty of the total hemispherical emissivity is estimated to be 0.01.

5 Conclusion

The spectral and total emissivities of precious metals gold, silver, palladium, platinum, rhodium, and iridium are sensitive to the roughness even if the optical roughness is smaller than 0.01. Structural defects caused by the roughening affect the spectral and total emissivities by no more than 0.02. The smoothest surfaces processed by polishing or turning by diamond have the lowest emissivities. The highest emissivities are obtained for the surfaces treated by lapping, independently of the roughness heights they have. The emissivity does not monotonically depend on the roughness height but rather correlates with slopes of the surface profile sections. This is in qualitative agreement with predictions of the theoretical works published recently.

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