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A systematic database of thin-film measurements by EPMA

Part I – Aluminum films

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A systematic database of thin-film measurements on aluminum films by electron probe microanalysis is presented. The measurements were performed between 3 and 30 kV accelerating voltage on films of six different nominal thicknesses, ranging from 100 up to 3200 Å, which were deposited simultaneously on 20 different substrates, ranging between Be and Bi. The purpose of this work was to provide systematic data on which existing and future thin-film analysis programs can be tested. A total of 1060 *k* ratios for the film element Al were collected and 872 *k* ratios for the various substrate elements from underneath the films. Tests with our own most recent thin-film analysis program, TFA, based on the double Gaussian PROZA96 procedure, on this database showed excellent performance: a mean value of 1.0093 for k_{calc}/k_{meas} and a relative root-mean-square deviation of 4.2457% in the histogram for the film element.

INTRODUCTION

The purpose of thin-film correction procedures in electron probe microanalysis (EPMA) is to convert the measured x-ray intensities from film (and/or substrate) elements into the correct thickness and composition of a film on a substrate. It will be obvious that this conversion can only be made correctly if it is exactly known where the x-rays are being produced as a function of depth in the specimen. This knowledge is commonly presented in terms of so-called $\phi(\rho z)$ curves, in which ϕ represents the number of x-ray photons produced and ρz the mass depth (product of density ρ and linear depth z).

Although the correct analytical description of $\phi(\rho z)$ curves in pure bulk elements and compounds over a wide range in experimental conditions is difficult enough in itself, it appears that a number of modern $\phi(\rho z)$ models[1–7] are very successful in this respect. This can be judged from their impressive performance on the most difficult analytical cases, e.g. the bulk analysis of the ultra-light elements B, C, N and O.[3–8]

Nevertheless, a typical example of bulk analysis in specimens which are supposed to be homogeneous in depth must be considered as relatively simple compared with cases of thin-film analysis where the geometry is much more complex, and where sharp discontinuities exist at the interfaces between film(s) and substrate. The question arises, therefore, of how the x-ray generation as a function of mass depth should be described analytically for each of the elements in a film–substrate combination, in the case that such discontinuities are present at each of the interfaces.

A number of approaches have been presented in the literature to deal with this problem. These are either based on (semi-)empirical approaches,[9–15] in which the $\phi(\rho z)$ curves of each of the film elements are modified empirically according to the specific film–substrate combination at hand, or on more fundamental approaches using Monte Carlo procedures.[16,17]

In a number of previous papers[18–20] on the subject, we have given a general outline of the approach we developed in our own analytical description of $\phi(\rho z)$ curves for the elements in a film–substrate combination, and the description of this procedure will briefly be repeated here.

The simplest case of a thin film–substrate combination that can be conceived is that of two neighbouring elements in the periodic system. Since the processes of electron scattering and deceleration and those of x-ray generation will be virtually the same in both elements, the $\phi(\rho z)$ curves for film and substrate elements will be almost identical. As a result, either of them could be used to calculate the generated and emitted intensities from film and substrate elements by partial integration between the appropriate limits. This simple approximation is known to work well as long as the difference in atomic number between film and substrate element does not exceed, say, 3–4 units. With increasing difference in atomic number the difference in electron scattering properties between film and substrate elements becomes noticeable and the x-ray production in the film can be influenced substantially. If the substrate element is heavier, then the x-ray production in the film will be increased, and vice versa. Therefore, a correction has to be applied in order to deal with such differences.

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In our latest $\phi(\rho z)$ bulk correction program (PROZA96[6]), which is based on a double Gaussian description of $\phi(\rho z)$ curves,[7] we use, as the independent input parameters, the surface ionization $\phi(0)$, the position (ρz_m) of the maximum in $\phi(\rho z)$, the exponent (α) in the right-hand descending Gaussian branch, and the value of the integral of $\phi(\rho z)$ (area under the $\phi(\rho z)$ curve, FI). The latter is calculated using the atomic number correction of Pouchou and Pichoir.[21]

Using these four independent shape parameters, the shape of the $\phi(\rho z)$ curve is completely determined; the value of the exponent in the left-hand ascending Gaussian branch (β) is calculated as a dependent variable.

Turning back to the case of a thin film on a substrate, we start from the basic assumption that the four independent Gaussian shape parameters for the $\phi(\rho z)$ curves of each of the elements in the film vary between two extremes, which are typical of either extremely thin or extremely thick layers. In the latter case it will be clear that the bulk parameters of the film element in question will be approached. In the former case, on the other hand, the parameters can be approximated by treating the film element as if it were solved in the substrate. In all intermediate cases the parameters will have to be composed from the two extremes, using weighting procedures, in which the Gaussian parameters for each particular element in each of the layers and in the substrate are assigned specific weights, depending upon the distance from the layer examined.

Furthermore, it is assumed that the ρz scale in each particular $\phi(\rho z)$ curve is continuous across interfaces, and that for each element in the film–substrate system only one continuous $\phi(\rho z)$ curve needs to be calculated.

Finally, it is assumed that only the $\phi(\rho z)$ curves for the film elements are affected by the nature and the thickness of the other films and the substrate, whereas those for the substrate elements are not. Whereas the former assumption seems to be reasonable, experimental evidence will have to show whether the assumption for the substrate elements really holds. This is precisely one of the reasons why, in our opinion, systematic databases of thin-film measurements of the kind we supply here are extremely useful.

It is obvious that the procedure proposed here is based on a number of simplifying assumptions and it is only fair to say that these are not always corroborated by, e.g., Monte Carlo simulations.[17] These simulations often show that the $\phi(\rho z)$ curves in the vicinity of an interface are not always smoothly varying Gaussians. In fact, they are often not smooth functions at all and they may show strong and rather unpredictable perturbations. It is very interesting, therefore, to find out how well our procedure performs in practice, in spite of the severe simplifications used inside.

The ideal thin-film correction procedure would be expected to calculate the correct emitted x-ray intensities for a given film thickness and composition, regardless of the nature of the substrate and the accelerating voltage used. It is questionable to what extent the existing procedures are indeed capable of such performance, because in our opinion there is a lack of systematic data on which the performance can be tested. An analysis of the available data in the literature[9,12–16] shows that, in spite of the fairly large number of data, there are only a limited number of film–substrate combinations with extreme differences in atomic number. Besides, there appears to be a strong bias towards films deposited on Si substrates, for obvious reasons. We therefore decided to set up large and systematic databases which contain measurements on a wide variety of film thicknesses of several elements, deposited on a wide range of substrates, ranging from Be to Bi, and measured over a wide range of accelerating voltages. In this paper, our results on aluminum films of six different thicknesses are reported.

STRUCTURAL DETAILS OF OUR OWN THIN-FILM APPROACH

Our thin-film treatment is essentially based on our latest PROZA[6] bulk correction program (PROZA96), in which a double Gaussian procedure is being used for a realistic description of $\phi(\rho z)$ curves. As pointed out before,[6] however, we use a modified version of the original Merlet[7] procedure in the sense that we use the quantities $\phi(0)$ (surface ionization), ρz_m [the position of the maximum in $\phi(\rho z)$], FI [the integral of $\phi(\rho z)$, or the area under the $\phi(\rho z)$ curve], and α (the exponent in the right-hand descending Gaussian) as the four necessary independent variables. The dependent variable β, which is used for the description of the left-hand ascending Gaussian, is calculated through an iterative mathematical procedure.

In the discussion on our thin-film approach that now follows, the superscript i will be used to denote the particular element under consideration, and the subscripts b, f and s will be used to indicate whether we are dealing with bulk, film, or substrate quantities.

The actual thin-film procedure starts with the calculation of the bulk standard intensities for all of the elements in the film–substrate combination. To this end, the α, $\phi(0)$, ρz_m and FI values for each element i are being calculated according to the bulk PROZA96 program. In the same first step, the α-values for element i radiation in all other elements j in film and substrate are also calculated. In the next step, the α values for the film elements are composed on the basis of the bulk compositions in film and substrate to yield the $\alpha^i_{b,f}$ and $\alpha^i_{b,s}$ quantities. Both of the latter quantities will be used later in a weighting procedure to establish the final α^i value typical of the complete film–substrate combination. In a similar way, composed values of $\phi(0)$, ρz_m and FI for the bulk compositions of film and substrate are calculated for element i radiation.

The next and crucial step is to establish the depth of penetration $\boldsymbol{R}_x$ for each element i radiation. Since there is no strict 'end' to a Gaussian curve, this presents something of a problem. In a previous publication,[20] where the surface-centered Gaussian model[1] was used, this was solved by taking $2.5/\alpha^i_{\text{final}}$ for each specific element as a convenient measure, since this ratio was found to represent the depth at which the original surface-centered Gaussian had dropped to less than 0.2% of its fictitious starting value γ. In the double Gaussian model, α operates in the right-hand (descending) branch only; it lies at hand, therefore, to suppose that the position ρz_m, at which the maximum in $\phi(\rho z)$ occurs, has to be added to $2.5/\alpha^i_{\text{final}}$ in order to find the 'end' of the $\phi(\rho z)$ curve. However, the final α^i value is not known *a priori*, because it has yet to be calculated from the $\alpha^i_{b,f}$ and $\alpha^i_{b,s}$ values, using weighting laws that are supposed to weight the various contributions over the relevant mass depth region down to $\boldsymbol{R}_x$. Since $\boldsymbol{R}_x$ is not known either, it is necessary to start an iterative procedure to arrive at the final α value and, hence, $\boldsymbol{R}_x$. The first (crude) estimate for $\boldsymbol{R}_x$ is obtained by averaging the constituent $(\rho z^i_{\mathrm{m}} + 2.5/\alpha^i)$ values in the bulk of the film and the substrate, and this mean value can then be used to generate a first estimate for $\boldsymbol{R}_x$. Next, a more accurate weighting procedure is started, in which the weight ($\boldsymbol{p}$) of each contribution as a function of mass depth (ρz) is described by a fourth-degree polynomial:

$$\boldsymbol{p}(\rho z) = \boldsymbol{N}(\rho z - \boldsymbol{L})^2(\rho z - \boldsymbol{R})^2 \qquad (1)$$

where $\boldsymbol{L}$ and $\boldsymbol{R}$, which are both functions of $\boldsymbol{R}_x$ only, are the double roots on the left- and right-hand sides of the polynomial, and $\boldsymbol{N}$ is a normalization factor that ensures the normalization under the $\boldsymbol{p}(\rho z)$ curve. In fact, this weighting procedure is a variant to the one first used by Pouchou and Pichoir.[9] However, these authors used the polynomial weighting procedure in order to generate sets of fictitious bulk compositions, one set for each $\phi(\rho z)$ parameter, from which all necessary $\phi(\rho z)$ parameters in their double-parabolic model for each particular element in the film–substrate combination were subsequently calculated. In our approach, on the other hand, the weighting is much more direct since we use the basic Gaussian parameters in a straightforward way.

In the iterative procedure for the determination of $\boldsymbol{R}_x$, the roots used are $-0.4\ \boldsymbol{R}_x$ for $\boldsymbol{L}$ and $\boldsymbol{R}_x$ for $\boldsymbol{R}$. Using these roots, a new value for $\boldsymbol{R}_x$ is calculated by integration over the $\boldsymbol{p}$ function [Eqn (1)]. The resulting value is normalized by dividing it by the integral of $\boldsymbol{p}(\rho z)$ between 0 and $\boldsymbol{R}$. The newly obtained $\boldsymbol{R}_x$ value is now compared with the previous one, and if the relative deviation is smaller than, say, 0.1%, the iteration procedure is stopped. If not, the latest $\boldsymbol{R}_x$ value is used to generate new $\boldsymbol{L}$ and $\boldsymbol{R}$ values, and the weighting procedure is repeated until convergence is obtained. This is usually the case in less than three cycles.

The last problem that has to be solved is to find the $\boldsymbol{L}$ and $\boldsymbol{R}$ values, which apply to the weighting procedures aimed at finding the four independent Gaussian parameters, necessary to describe the $\phi(\rho z)$ curves for each of the elements in the film–substrate combination. These roots will be different for each of the Gaussian parameters. Provisional settings were found originally by a process of optimization on the (often conflicting) thin-film data from the literature. Later, these settings were fine-tuned by using our own databases, of which the present one on aluminum films is an example. It must be emphasized, however, that this fine-tuning process is merely necessary to find the proper translation from the old to the new model, where different parameters with their different meanings are involved. It is not possible to 'optimize' a vast database of measurements with the relatively few parameters at hand, certainly not if the experimental conditions vary widely, as in the present case.

The double roots for the four Gaussian parameters can be summarized as in Table 1. It is clear from this table that more weight is assigned to the deeper regions in the specimen as far as α is concerned, whereas $\phi(0)$ is mainly governed by the near-surface regions. Regarding the latter parameter, it is assumed that electrons scattered back from regions deeper than 0.5 $\boldsymbol{R}_x$ will not be able to make it back to the surface and, consequently, cannot contribute to $\phi(0)$.

Table 1. Double roots for the Gaussian parameters

Parameter	$\boldsymbol{L}$	$\boldsymbol{R}$
α	$-0.3\ \boldsymbol{R}_x$	$\boldsymbol{R}_x$
ρz_{m}	$-0.9\ \boldsymbol{R}_x$	$0.7\ \boldsymbol{R}_x$
FI	$-0.8\ \boldsymbol{R}_x$	$\boldsymbol{R}_x$
$\phi(0)$	$-0.5\ \boldsymbol{R}_x$	$0.5\ \boldsymbol{R}_x$

Once the Gaussian parameters for each of the elements in the film have been obtained, the emitted intensities can be calculated by partial integration;[6] those for the film elements between the ρz limits of zero and T (the film thickness) and for the substrate elements from T down to infinity. Appropriate corrections for absorption have, of course, to be made. Taking the ratios to the intensities emitted from the bulk standards will finally give the calculated k ratios which have to be compared with the measured values. This is, in short, the procedure followed in the present work. Normally, one would try to operate such a thin-film program the other way around, i.e. try to determine the thickness and/or composition of a film from measured k ratios. Full details of this procedure can be found in one of our previous publications.[20]

EXPERIMENTAL

Aluminum films of six different nominal thicknesses (10, 20, 40, 80, 160 and 320 nm) were deposited by vacuum evaporation on to polished pieces of 20 different substrate elements, ranging from Be to Bi, mounted in a single specimen mount. In order to avoid problems with simultaneously polishing materials with largely different hardnesses, small pieces of all substrate elements were mounted separately first in copper-filled mounting resin and polished carefully. Next, small rectangular blocks of mounting resin, each containing a polished substrate specimen, were cut out and remounted together to produce the final assembly of 20 polished substrate elements. In total, six such substrate assemblies were manufactured in order to accommodate six different film thicknesses.

During each vacuum deposition run, identical films were also deposited on crystals of rock salt and Si wafers. The former specimens were to be used for independent determination of the film thicknesses by Rutherford backscattering spectroscopy (RBS), whereas the latter served incidentally for transmission electron microscopy (TEM) investigations of cross-sections.

The films deposited on rock salt could be lifted off easily by dissolving the salt in water. These specimens, when picked up on a TEM grid, were eminently suited to perform intensity measurements on unsupported films. In combination with the measurements on the same films on a variety of substrates, this provided the experimental possibility of accessing the surface ionization value $\phi(0)$ by a process of extrapolation towards a film thickness of zero. This will be the subject of a future paper.

The microprobe measurements on the film (Al) and the substrate elements were carried out at accelerating voltages between 3 and 30 kV, using JEOL 733 and 8600 electron probe microanalyzers. Both instruments have x-ray take-off angles of 40°.

RESULTS

Establishing the real thicknesses of the films turned out to be a major problem; therefore, our primary efforts were concerned with this task. To begin with, there were only two really independent sources of information: RBS (carried out at Philips Research Laboratories, Eindhoven, The Netherlands) and Monte Carlo calculations.[17] In the latter approach the mass thicknesses are determined by iterative procedures, in which the results of the simulations are compared with the experimental measurements. The results obtained by the two techniques differed markedly, as can be judged from Table 2.

Assuming a bulk density of 2.70 g cm^{-3} for aluminum, the mass thicknesses aimed at would be 2.70, 5.40, 10.80, 21.60, 43.20, and 86.40 μg cm^{-2}. It is clear that, e.g., RBS finds much larger thicknesses for the three thinner films, whereas for the thicker films increasingly lower film thicknesses are found. With the Monte Carlo method, very much larger thicknesses are found than either the nominal or the RBS values over the full range.

The following remarks can be made concerning Table 2, where the paragraph letters below correspond to the footnote letters in the table.

(a) The Monte Carlo program, using the measured k ratios for Al Kα, was found to produce a consistent variation of 20% in the mass thicknesses between 3 and 30 kV, starting low and ending high, for both substrates. However, the results for a specific fixed voltage were virtually independent of the atomic number of the substrate, which must be considered as a remarkably good achievement. The mean results over the voltage range have been reported here.

(b) The GMR film program is the computer program written by Waldo.[13,22] We used the option in this program which is entirely based on the PAP[9] (double-parabolic) procedure. This program was found to produce up to 14% variation in mass thicknesses on going from a Be to a Bi substrate for a fixed accelerating voltage. On the other hand, the dependence on accelerating voltage was much better. The results calculated for a Ti substrate, representing only moderate differences in atomic number between film and substrate elements, are presented here.

Table 2. Aluminum films: reported values are mass thicknesses in μg cm^{-2}

Nominal	RBS	Monte Carlo[a] On Be	Monte Carlo[a] On Bi	GMR[b] film on Ti	TFA[c] program on Ti	Database[d]
2.70	3.27	3.57	3.47	3.58	3.62	3.55
5.40	6.14	7.20	6.96	6.95	7.06	7.04
10.80	11.96	14.26	13.66	13.69	13.95	13.80
21.60	21.86	24.99	24.92	25.04	25.56	24.90
43.20	39.46	48.84	49.23	48.54	49.84	49.20
86.40	81.97	88.90	88.07	84.66	87.11	85.40

[a–d] See the corresponding paragraphs (a)–(d) in the text.

(c) The TFA program, based on our own modification[2] of the surface-centered Gaussian Packwood/Brown approach,[1] is a predecessor to our present thin-film analysis program. Its results varied by less than 5% between a Be and a Bi substrate and the results as a function of voltage were satisfactory. As was the case with the GMR program, the results calculated for a Ti substrate are presented here. It is clear that the results from the GMR and TFA programs do not show pronounced differences. In addition, they both show fair agreement with the mean results of the Monte Carlo program, contrary to the RBS results in many cases.

(d) The last column in Table 2 represents the mass thicknesses which were finally adopted in our database. The values are very close to the mean numbers in the other columns.

It is remarkable that, with none of the techniques used, the expected ratio in the mass thicknesses of 1 : 2 : 4 : 8 : 16 : 32, which was aimed at during the preparation of the films and which was supposed to be easy to achieve, was in fact attained. With RBS the ratios obtained were 1 : 1.88 : 3.66 : 6.69 : 12.07 : 25.07 and with Monte Carlo (mean) 1 : 2.01 : 3.97 : 7.09 : 13.94 : 25.14. With the EPMA programs GMR film and TFA sequences of 1 : 1.94 : 3.82 : 6.99 : 13.56 : 23.65 and 1 : 1.95 : 3.85 : 7.06 : 13.77 : 24.06 were calculated, respectively.

In an isolated case (nominal 800 Å, or 21.60 μg cm^{-2}), a film on NaCl was investigated in a cross-section in the transmission electron microscope (JEOL 2000 FX). Thicknesses corresponding to 25 μg cm^{-2} (assuming the bulk density for Al) and slightly higher were thereby found, thus corroborating the Monte Carlo and EPMA (GMR and TFA) results, rather than the RBS data. Apparently, it is extremely difficult to find the 'true' film thicknesses. However, we want to emphasize most strongly that, even if the true film thicknesses will presumably never be known with 100% certainty, the measurements on such (our present) specimens are still extremely useful because it can safely be assumed that the same mass thickness applies to each of the various substrates.

The EPMA measurements for Al Kα were carried out as a function of atomic number of the substrate, starting with Be and ending with Bi for each specific accelerating voltage. After calibration of the Al Kα peak with a TAP analyzer crystal on the Al bulk standard, a minimum of 10 intensity measurements were performed in each case and the mean k ratio was used as the entry in the final database. This measuring procedure has the specific advantage of disclosing immediately any erratic behavior in the variation of the intensity of the Al Kα peak with atomic number of the substrate, a variation which must be assumed to be smooth. Moreover, one would expect the signal to increase monotonically with the atomic number of the substrate. Any sudden increase in the signal might point to a case of fluorescence, e.g. if the Al film is on a Si substrate.

Figure 1 shows some of the results which can typically be obtained in the measurements as a function of atomic number of the substrate at an accelerating voltage of 15 kV for the films with nominal thicknesses of 100 (top) and 400 Å (bottom).

Figure 2 shows similar results, but now for the film with a nominal thickness of 800 Å, at accelerating voltages of 20 (top) and 25 kV (bottom).

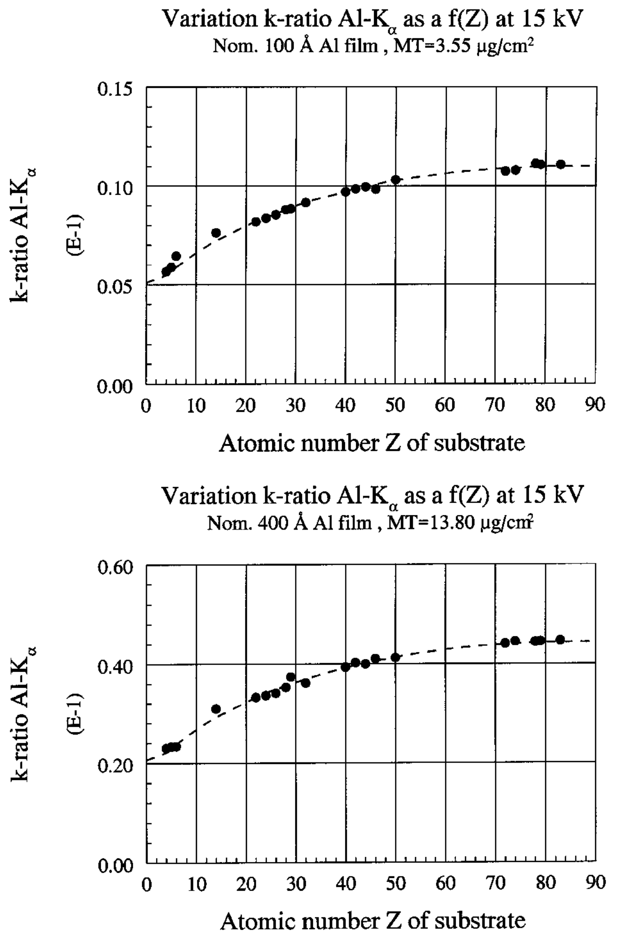

Figure 1. Variation of the k ratios for Al Kα as a function of the atomic number of the substrate at 15 kV. Top, nominal thickness 100 Å, assumed mass thickness 3.55 μg cm^{-2}; bottom, nominal thickness 400 Å, assumed mass thickness 13.80 μg cm^{-2}. Solid circles represent the measurements and the broken curves show the predictions of the TFA program. X-ray take-off angle, 40°.

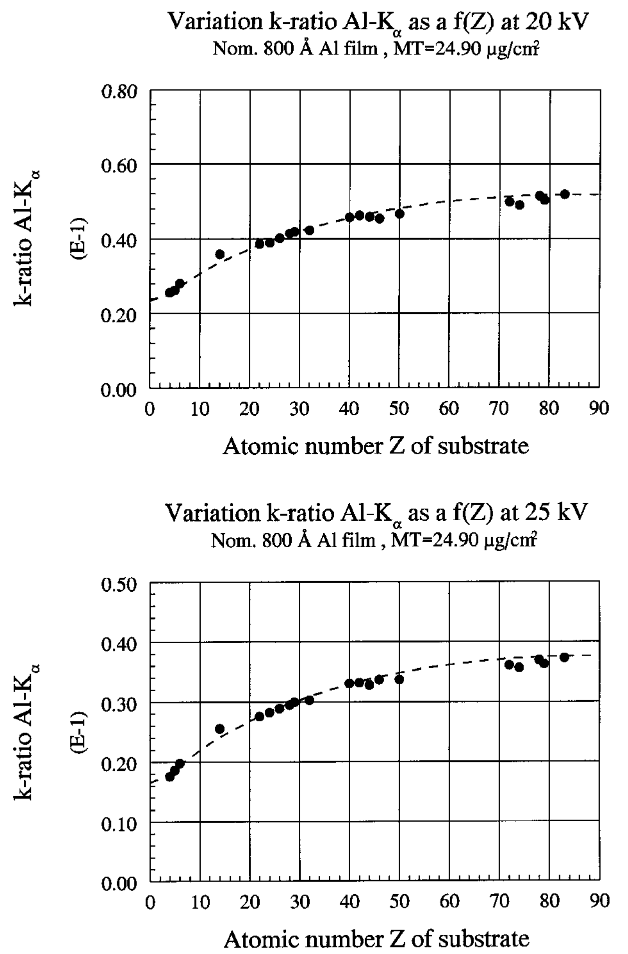

Figure 2. Variation of the k ratios for Al Kα as a function of the atomic number of the substrate for an aluminum film of nominal thickness 800 Å, assumed mass thickness 24.90 μg cm^{-2}. Top, at 20 kV; bottom, at 25 kV. Solid circles represent the measurements and the broken curves show the predictions of the TFA program. X-ray take-off angle, 40°.

It is evident from these results that remarkable agreement exists between the measurements and the calculations and that, in general, measurements with a smooth variation can indeed be obtained. The only case where noticeable and persistent deviations exist is where a silicon substrate ($Z = 14$) is involved, and this must be attributed to fluorescence.

Since the Al Kα intensities emitted from the films are a function not only of the atomic number of the substrate, but also of that of the applied accelerating voltage, it is meaningful to present the results also as a function of the accelerating voltage for the six films for a fixed substrate. This is done in Fig. 3 for the beryllium (top) and titanium (bottom) substrates and in Fig. 4 for the molybdenum (top) and tungsten (bottom) substrates. Again, the agreement between measurements and calculations is remarkably good.

In view of the huge number of measured data collected in the present investigation (1060 k ratios for Al Kα from the film element and 872 k ratios from the substrate elements), it is impossible to judge the overall performance of the present TFA program (or any other thin-film program, for that matter) by mere inspection of a relatively small number of graphical representations of the measured and calculated results. We chose, therefore, an approach which is commonly used in tests on the performance of bulk correction programs. In this approach the k ratio (k') for the given entry in the database under the specific experimental conditions is calculated and compared with the measured value (k). The ratio k'/k is then displayed in a histogram, showing the number of analyses vs the value of k'/k, and the narrowness of the histogram (in terms of the relative root-mean-square value in %), together with the mean value of the distribution are then used as a final measure of success. Figure 5 shows the results which were obtained in the present case. The results must be regarded as excellent, certainly if one takes into consideration that in a number of cases (which have still been included in the final database) the experimental conditions for thin-film analysis are not suitable at all. Examples of these cases are when the accelerating voltage for a given film thickness is simply too low, so that the $\phi(\rho z)$ curve for the film element barely touches on the substrate. It is evident that the results could become very much better if such cases were eliminated from the database.

As mentioned before, a wide variety of substrate elements was also measured from underneath the films. All possible x-ray lines that could be excited were measured

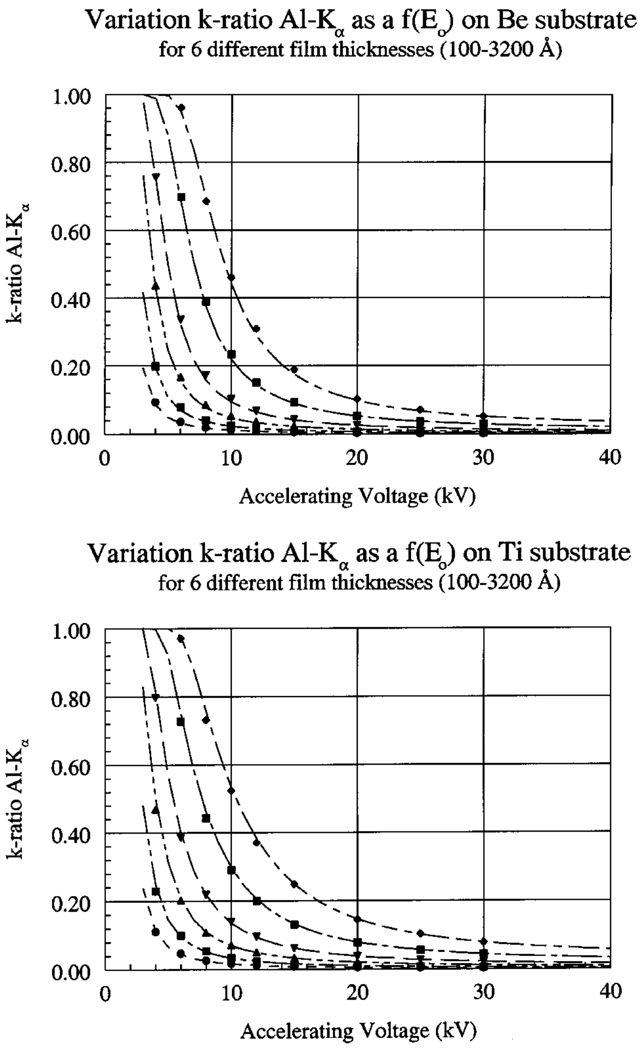

Figure 3. Variation of the k ratios for Al Kα as a function of accelerating voltage for the six aluminum films of nominal thicknesses ranging between 100 and 3200 Å. Top, for a beryllium substrate; bottom, for a titanium substrate. Symbols represent the measurements and the broken curves show the predictions of the TFA program. X-ray take-off angle, 40°.

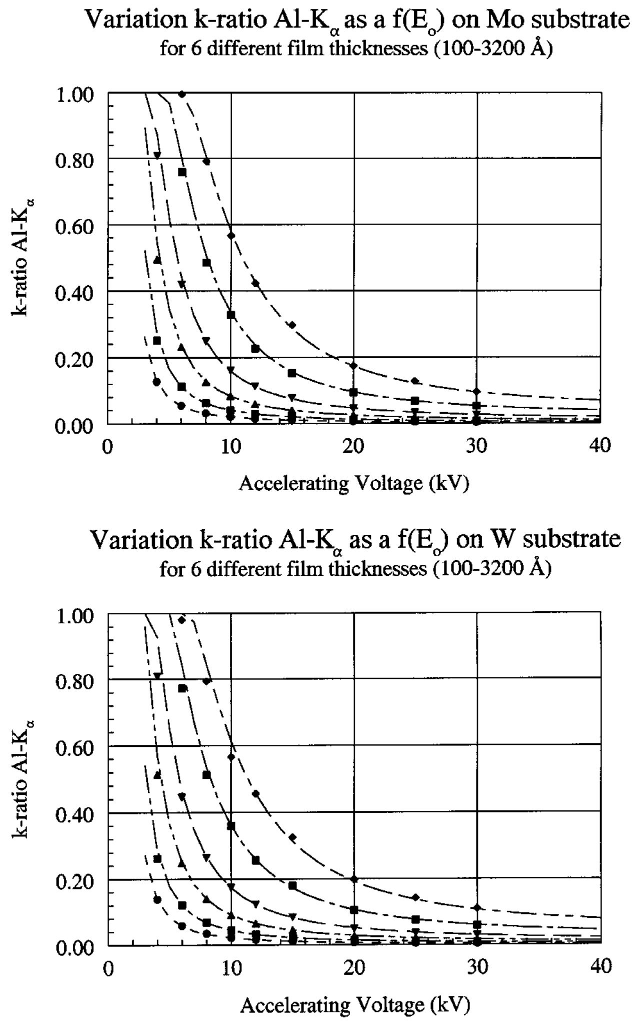

Figure 4. Variation of the k ratios for Al Kα as a function of accelerating voltage for the six aluminum films of nominal thicknesses ranging between 100 and 3200 Å. Top, for a molybdenum substrate; bottom, for a tungsten substrate. Symbols represent the measurements and the broken curves show the predictions of the TFA program. X-ray take-off angle, 40°.

and the k ratios were also included in one large data file. Figure 6 shows the results obtained for the silicon (top) and titanium (bottom) substrates, and Fig. 7 gives similar results for the much heavier germanium (top) and molybdenum (bottom) substrates. Again, it appears evident that satisfactory agreement is obtained between calculations and measurements, with very few exceptions. The latter are connected again with those cases where the conditions for thin-film analysis are unsuitable: when the accelerating voltage for the film thickness at hand is low and the $\phi(\rho z)$ curve hardly extends into the substrate. The results of the overall statistical analysis for the substrate elements, similar to the one performed before for the film element, are shown in Fig. 8. After the elimination of the results obtained under totally unsuitable experimental conditions, most satisfactory mean k'/k (1.0125) and r.m.s. values (3.6670%) are obtained. Full details of the complete database can be found in the Appendix and/or are available from the authors.

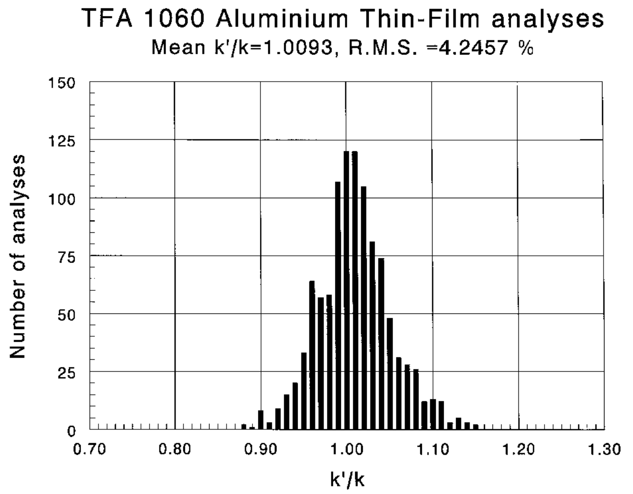

Figure 5. Histogram obtained with the TFA thin-film program on 1060 Al Kα analyses, measured between 3 and 30 kV, from aluminum films of six different mass thicknesses. The number of analyses is displayed vs the ratio k'/k between the calculated (k') and the measured k ratio (k).

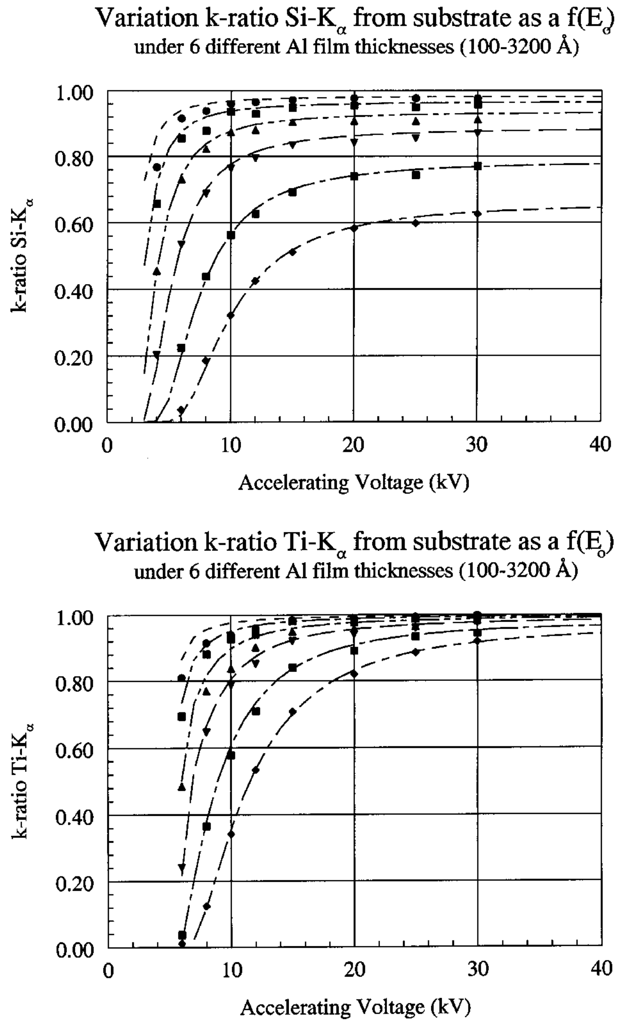

Figure 6. Variation of the k ratios for the substrate elements as a function of accelerating voltage from underneath the six aluminum films of nominal thicknesses ranging between 100 and 3200 Å. Top, silicon substrate; bottom, titanium substrate. Symbols represent the measurements and the broken curves show the predictions of the TFA program. X-ray take-off angle, 40°.

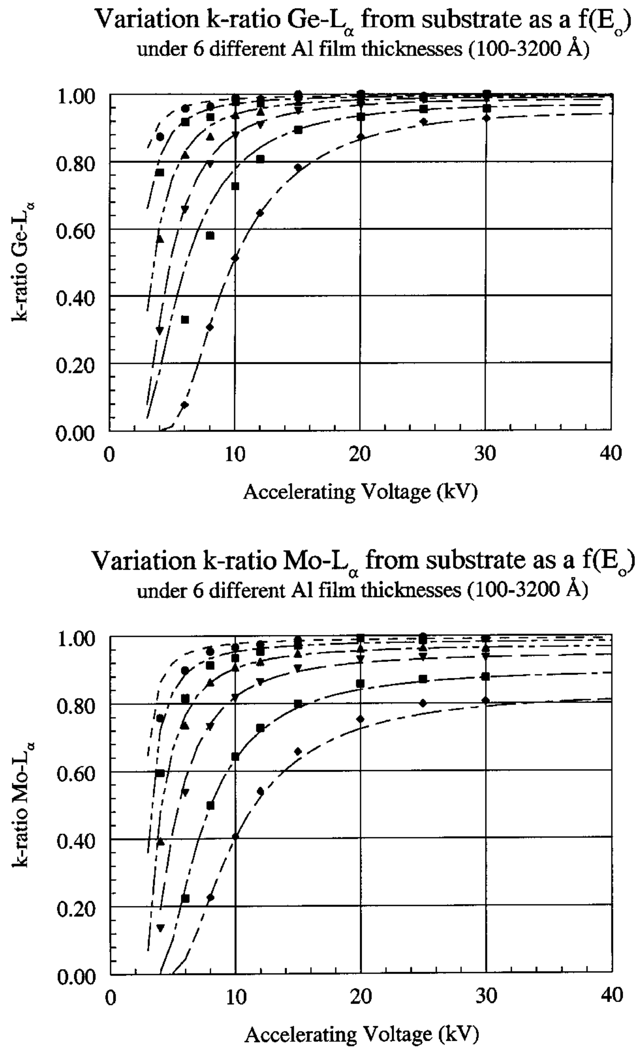

Figure 7. Variation of the k ratios for the substrate elements as a function of accelerating voltage from underneath the six aluminum films of nominal thicknesses ranging between 100 and 3200 Å. Top, germanium substrate; bottom, molybdenum substrate. Symbols represent the measurements and the broken curves show the predictions of the TFA program. X-ray take-off angle, 40°.

DISCUSSION

The results presented in this paper clearly show that accurate analysis of thin films over a wide range of experimental conditions is possible, especially if the accelerating voltage used in the measurements is suitable for the specific film thickness at hand. In all cases it is advisable to apply a sufficiently high voltage so that the $\phi(\rho z)$ curve of the film element extends relatively deep into the substrate. In other words, the mass thickness of the film should represent only a minor fraction of the total range of $\phi(\rho z)$.

As Figs 1 and 2 indicate, the calculations of the intensities emitted from a film with given mass thickness for a wide variety of substrates closely follow the measurements. This means that if the TFA program were to be used the other way around, virtually constant thicknesses would be found, irrespective of the atomic number of the substrate. This is, of course, one of the two major goals mentioned in the Introduction.

The other major goal was that the calculations would closely follow the measurements as a function of accelerating voltage for a given film thickness on a specific substrate. The success of these calculations can be judged from Figs 3 and 4 for a small selection of substrates, ranging from Be to Bi. The only noticeable deviations can be found in cases where the conditions are not suitable: low accelerating voltage, heavy substrate, e.g. W, and thick film (Fig. 4, bottom). If such results were to be excluded from the histogram in Fig. 5, then, of course, very much improved results could be obtained.

The fact that the mean k'/k value comes out closely around 1.0 means, of course, nothing else than that the k ratios that we calculate agree closely with those expected from the mass thicknesses adopted in Table 2. If one were to insist on adopting the RBS values, then systematic shifts in the centering of the histogram would be observed. What we consider of much more importance, however, is the narrowness in the histogram, which reflects the ability of the program to yield a remarkably consistent

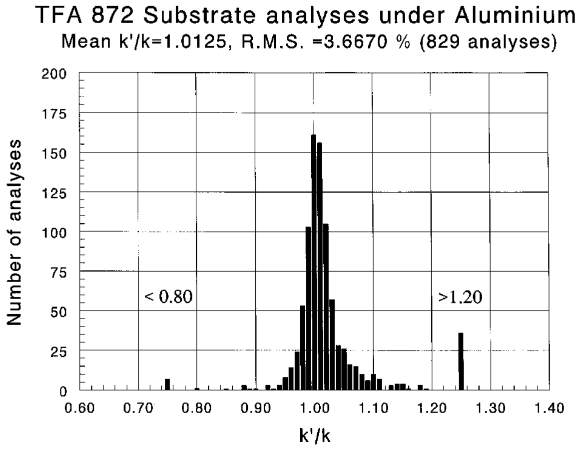

Figure 8. Histogram obtained with the TFA thin-film program on 872 substrate element analyses, measured between 3 and 30 kV, from underneath the aluminum films of six different mass thicknesses. The number of analyses is displayed vs the ratio between the calculated (k') and the measured k ratio (k). The reported mean k'/k and r.m.s. values apply to only 829 analyses because the statistical flyers have been accumulated in the two bars at $k'/k = 0.75$ (7 analyses with $k'/k < 0.80$) and $k'/k = 1.25$ (36 analyses with $k'/k > 1.20$), and have been excluded from the final evaluation.

mass thickness over a wide range of atomic numbers of the substrates and a large range in accelerating voltage. Any statement about a systematic error requires an exact knowledge about the true ‘reference’ value, which will presumably never be known.

As far as the substrate elements are concerned, similar remarks apply as in the case of the film element: low accelerating voltages for relatively thick films should be avoided, although, surprisingly, there are also problems sometimes with the thinnest films, for no good reason (Figs 6 and 7). Obviously, it can be difficult enough to measure k ratios which differ only very slightly from unity. This observation, in conjunction with the fact that the slightest deviation in the substrate k ratio can produce a large deviation in the mass thickness of the film if the program is run the other way around, can make it somewhat tricky to use the measured k ratio of the substrate element exclusively in order to find the mass thickness of the film. In all cases much more weight should be assigned to the signals emitted by the film elements; after all, the emitted film signals are more or less directly proportional to the film thickness.

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APPENDIX

Data file for aluminum films (take-off angle 40°). Substrate line: K = 0, L = 1, M = 2

No.	$Z_{substrate}$	Mass thickness (μg cm^{-2})	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
1	4	3.55	0.18981	—	3	0
2	4	3.55	0.09317	—	4	0
3	4	3.55	0.03595	—	6	0
4	4	3.55	0.01986	—	8	0
5	4	3.55	0.01277	—	10	0
6	4	3.55	0.00872	—	12	0
7	4	3.55	0.00566	—	15	0

No.	$Z_{substrate}$	Mass thickness (μg cm^{-2})	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
8	4	3.55	0.00346	—	20	0
9	4	3.55	0.00249	—	25	0
10	4	3.55	0.00193	—	30	0
11	4	7.04	0.19872	—	4	0
12	4	7.04	0.07860	—	6	0
13	4	7.04	0.04064	—	8	0
14	4	7.04	0.02520	—	10	0
15	4	7.04	0.01700	—	12	0
16	4	7.04	0.01122	—	15	0
17	4	7.04	0.00698	—	20	0
18	4	7.04	0.00498	—	25	0
19	4	7.04	0.00391	—	30	0
20	4	13.80	0.43663	—	4	0
21	4	13.80	0.16644	—	6	0
22	4	13.80	0.08548	—	8	0
23	4	13.80	0.05330	—	10	0
24	4	13.80	0.03606	—	12	0
25	4	13.80	0.02294	—	15	0
26	4	13.80	0.01368	—	20	0
27	4	13.80	0.00968	—	25	0
28	4	13.80	0.00790	—	30	0
29	4	24.90	0.75558	—	4	0
30	4	24.90	0.33607	—	6	0
31	4	24.90	0.17336	—	8	0
32	4	24.90	0.10194	—	10	0
33	4	24.90	0.06770	—	12	0
34	4	24.90	0.04288	—	15	0
35	4	24.90	0.02558	—	20	0
36	4	24.90	0.01760	—	25	0
37	4	24.90	0.01444	—	30	0
38	4	49.20	0.69750	—	6	0
39	4	49.20	0.38894	—	8	0
40	4	49.20	0.23268	—	10	0
41	4	49.20	0.15008	—	12	0
42	4	49.20	0.09314	—	15	0
43	4	49.20	0.05302	—	20	0
44	4	49.20	0.03653	—	25	0
45	4	49.20	0.02921	—	30	0
46	4	85.40	0.96110	—	6	0
47	4	85.40	0.68538	—	8	0
48	4	85.40	0.46017	—	10	0
49	4	85.40	0.30884	—	12	0
50	4	85.40	0.18818	—	15	0
51	4	85.40	0.10182	—	20	0
52	4	85.40	0.06966	—	25	0
53	4	85.40	0.05064	—	30	0
54	5	3.55	0.19267	—	3	0
55	5	3.55	0.09380	—	4	0
56	5	3.55	0.03647	—	6	0
57	5	3.55	0.02014	—	8	0
58	5	3.55	0.01318	—	10	0
59	5	3.55	0.00906	—	12	0
60	5	3.55	0.00588	—	15	0
61	5	3.55	0.00380	—	20	0
62	5	3.55	0.00272	—	25	0
63	5	3.55	0.00216	—	30	0
64	5	7.04	0.20040	—	4	0
65	5	7.04	0.08076	—	6	0
66	5	7.04	0.04210	—	8	0
67	5	7.04	0.02624	—	10	0
68	5	7.04	0.01740	—	12	0
69	5	7.04	0.01176	—	15	0
70	5	7.04	0.00724	—	20	0
71	5	7.04	0.00518	—	25	0
72	5	7.04	0.00410	—	30	0
73	5	13.80	0.43033	—	4	0
74	5	13.80	0.16858	—	6	0
75	5	13.80	0.08550	—	8	0

No.	$Z_{substrate}$	Mass thickness ($\mu g\ cm^{-2}$)	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
76	5	13.80	0.05382	—	10	0
77	5	13.80	0.03618	—	12	0
78	5	13.80	0.02326	—	15	0
79	5	13.80	0.01410	—	20	0
80	5	13.80	0.01020	—	25	0
81	5	13.80	0.00782	—	30	0
82	5	24.90	0.74330	—	4	0
83	5	24.90	0.34012	—	6	0
84	5	24.90	0.17774	—	8	0
85	5	24.90	0.10538	—	10	0
86	5	24.90	0.07052	—	12	0
87	5	24.90	0.04482	—	15	0
88	5	24.90	0.02620	—	20	0
89	5	24.90	0.01860	—	25	0
90	5	24.90	0.01446	—	30	0
91	5	49.20	0.69536	—	6	0
92	5	49.20	0.39180	—	8	0
93	5	49.20	0.23654	—	10	0
94	5	49.20	0.15214	—	12	0
95	5	49.20	0.09728	—	15	0
96	5	49.20	0.05542	—	20	0
97	5	49.20	0.03838	—	25	0
98	5	49.20	0.02944	—	30	0
99	5	85.40	0.97070	—	6	0
100	5	85.40	0.68598	—	8	0
101	5	85.40	0.45740	—	10	0
102	5	85.40	0.30778	—	12	0
103	5	85.40	0.18986	—	15	0
104	5	85.40	0.10368	—	20	0
105	5	85.40	0.07078	—	25	0
106	5	85.40	0.05358	—	30	0
107	6	3.55	0.19178	—	3	0
108	6	3.55	0.09175	—	4	0
109	6	3.55	0.03594	—	6	0
110	6	3.55	0.01884	—	8	0
111	6	3.55	0.01216	—	10	0
112	6	3.55	0.00928	—	12	0
113	6	3.55	0.00644	—	15	0
114	6	3.55	0.00391	—	20	0
115	6	3.55	0.00273	—	25	0
116	6	3.55	0.00205	—	30	0
117	6	7.04	0.19378	—	4	0
118	6	7.04	0.07876	—	6	0
119	6	7.04	0.03944	—	8	0
120	6	7.04	0.02474	—	10	0
121	6	7.04	0.01761	—	12	0
122	6	7.04	0.01187	—	15	0
123	6	7.04	0.00740	—	20	0
124	6	7.04	0.00520	—	25	0
125	6	7.04	0.00406	—	30	0
126	6	13.80	0.41722	—	4	0
127	6	13.80	0.16378	—	6	0
128	6	13.80	0.08436	—	8	0
129	6	13.80	0.05404	—	10	0
130	6	13.80	0.03602	—	12	0
131	6	13.80	0.02334	—	15	0
132	6	13.80	0.01462	—	20	0
133	6	13.80	0.01067	—	25	0
134	6	13.80	0.00812	—	30	0
135	6	24.90	0.71248	—	4	0
136	6	24.90	0.32984	—	6	0
137	6	24.90	0.17750	—	8	0
138	6	24.90	0.10596	—	10	0
139	6	24.90	0.07134	—	12	0
140	6	24.90	0.04538	—	15	0
141	6	24.90	0.02803	—	20	0
142	6	24.90	0.01977	—	25	0
143	6	24.90	0.01520	—	30	0

No.	$Z_{substrate}$	Mass thickness ($\mu g\ cm^{-2}$)	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
144	6	49.20	0.66364	—	6	0
145	6	49.20	0.37756	—	8	0
146	6	49.20	0.22920	—	10	0
147	6	49.20	0.14986	—	12	0
148	6	49.20	0.09580	—	15	0
149	6	49.20	0.05627	—	20	0
150	6	49.20	0.03916	—	25	0
151	6	49.20	0.03035	—	30	0
152	6	85.40	0.94594	—	6	0
153	6	85.40	0.67848	—	8	0
154	6	85.40	0.45444	—	10	0
155	6	85.40	0.30700	—	12	0
156	6	85.40	0.18968	—	15	0
157	6	85.40	0.10604	—	20	0
158	6	85.40	0.07118	—	25	0
159	6	85.40	0.05394	—	30	0
160	14	3.55	0.20496	—	3	0
161	14	3.55	0.10778	0.76720	4	0
162	14	3.55	0.04493	0.91448	6	0
163	14	3.55	0.02466	0.93778	8	0
164	14	3.55	0.01638	0.95949	10	0
165	14	3.55	0.01121	0.96447	12	0
166	14	3.55	0.00762	0.97109	15	0
167	14	3.55	0.00496	0.97659	20	0
168	14	3.55	0.00361	0.97599	25	0
169	14	3.55	0.00275	0.97560	30	0
170	14	7.04	0.21944	0.65738	4	0
171	14	7.04	0.09397	0.85438	6	0
172	14	7.04	0.05072	0.87690	8	0
173	14	7.04	0.03218	0.93565	10	0
174	14	7.04	0.02224	0.92824	12	0
175	14	7.04	0.01524	0.94795	15	0
176	14	7.04	0.00952	0.95403	20	0
177	14	7.04	0.00682	0.94823	25	0
178	14	7.04	0.00566	0.95631	30	0
179	14	13.80	0.45748	0.45544	4	0
180	14	13.80	0.19246	0.73096	6	0
181	14	13.80	0.10400	0.82135	8	0
182	14	13.80	0.06710	0.87235	10	0
183	14	13.80	0.04620	0.87960	12	0
184	14	13.80	0.03093	0.90364	15	0
185	14	13.80	0.01912	0.90665	20	0
186	14	13.80	0.01410	0.90646	25	0
187	14	13.80	0.01102	0.91137	30	0
188	14	24.90	0.78246	0.20322	4	0
189	14	24.90	0.37372	0.53483	6	0
190	14	24.90	0.20770	0.68748	8	0
191	14	24.90	0.12844	0.76367	10	0
192	14	24.90	0.08842	0.79426	12	0
193	14	24.90	0.05850	0.83358	15	0
194	14	24.90	0.03582	0.84161	20	0
195	14	24.90	0.02556	0.85433	25	0
196	14	24.90	0.02044	0.86942	30	0
197	14	49.20	0.72061	0.22434	6	0
198	14	49.20	0.43088	0.43913	8	0
199	14	49.20	0.27402	0.56333	10	0
200	14	49.20	0.18708	0.62653	12	0
201	14	49.20	0.12256	0.69151	15	0
202	14	49.20	0.07478	0.73887	20	0
203	14	49.20	0.05250	0.74262	25	0
204	14	49.20	0.04152	0.77000	30	0
205	14	85.40	0.96472	0.03730	6	0
206	14	85.40	0.71610	0.18494	8	0
207	14	85.40	0.49914	0.32185	10	0
208	14	85.40	0.35380	0.42538	12	0
209	14	85.40	0.22992	0.51104	15	0
210	14	85.40	0.13518	0.58221	20	0
211	14	85.40	0.09382	0.59740	25	0

No.	$Z_{substrate}$	Mass thickness (μg cm^{-2})	*k* (Al Kα)	*k* (substrate)	Accelerating voltage (kV)	Substrate line
212	14	85.40	0.07394	0.62524	30	0
213	22	3.55	0.21066	—	3	0
214	22	3.55	0.11107	—	4	0
215	22	3.55	0.04766	0.80955	6	0
216	22	3.55	0.02679	0.91419	8	0
217	22	3.55	0.01762	0.93847	10	0
218	22	3.55	0.01226	0.95888	12	0
219	22	3.55	0.00818	0.98349	15	0
220	22	3.55	0.00534	0.99000	20	0
221	22	3.55	0.00382	0.99337	25	0
222	22	3.55	0.00293	0.99777	30	0
223	22	7.04	0.22875	—	4	0
224	22	7.04	0.10053	0.69460	6	0
225	22	7.04	0.05452	0.88046	8	0
226	22	7.04	0.03466	0.92616	10	0
227	22	7.04	0.02398	0.94008	12	0
228	22	7.04	0.01616	0.98089	15	0
229	22	7.04	0.01019	0.97665	20	0
230	22	7.04	0.00741	0.98680	25	0
231	22	7.04	0.00576	0.99399	30	0
232	22	13.80	0.46874	—	4	0
233	22	13.80	0.20186	0.48491	6	0
234	22	13.80	0.10816	0.76928	8	0
235	22	13.80	0.07130	0.83718	10	0
236	22	13.80	0.05040	0.90110	12	0
237	22	13.80	0.03324	0.94854	15	0
238	22	13.80	0.02055	0.95736	20	0
239	22	13.80	0.01519	0.96398	25	0
240	22	13.80	0.01161	0.98292	30	0
241	22	24.90	0.79698	—	4	0
242	22	24.90	0.38579	0.24122	6	0
243	22	24.90	0.21888	0.64575	8	0
244	22	24.90	0.13926	0.78693	10	0
245	22	24.90	0.09642	0.85127	12	0
246	22	24.90	0.06240	0.92038	15	0
247	22	24.90	0.03860	0.94062	20	0
248	22	24.90	0.02757	0.95999	25	0
249	22	24.90	0.02178	0.97487	30	0
250	22	49.20	0.72795	0.03735	6	0
251	22	49.20	0.44316	0.36589	8	0
252	22	49.20	0.29064	0.57759	10	0
253	22	49.20	0.19992	0.70950	12	0
254	22	49.20	0.13154	0.83966	15	0
255	22	49.20	0.07856	0.89027	20	0
256	22	49.20	0.05512	0.93257	25	0
257	22	49.20	0.04453	0.94416	30	0
258	22	85.40	0.97016	0.01062	6	0
259	22	85.40	0.73124	0.12301	8	0
260	22	85.40	0.52376	0.34172	10	0
261	22	85.40	0.37058	0.53330	12	0
262	22	85.40	0.24850	0.70714	15	0
263	22	85.40	0.14501	0.81991	20	0
264	22	85.40	0.10318	0.88462	25	0
265	22	85.40	0.07794	0.91875	30	0
266	24	3.55	0.23239	—	3	0
267	24	3.55	0.11430	—	4	0
268	24	3.55	0.04769	—	6	0
269	24	3.55	0.02752	0.91047	8	0
270	24	3.55	0.01788	0.96803	10	0
271	24	3.55	0.01221	0.96432	12	0
272	24	3.55	0.00836	0.97180	15	0
273	24	3.55	0.00547	0.98485	20	0
274	24	3.55	0.00386	0.98619	25	0
275	24	3.55	0.00292	0.98997	30	0
276	24	7.04	0.23965	—	4	0
277	24	7.04	0.10403	—	6	0
278	24	7.04	0.05626	0.87213	8	0
279	24	7.04	0.03456	0.92704	10	0

No.	$Z_{substrate}$	Mass thickness (μg cm^{-2})	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
280	24	7.04	0.02484	0.94725	12	0
281	24	7.04	0.01656	0.96321	15	0
282	24	7.04	0.01020	0.98391	20	0
283	24	7.04	0.00728	0.98403	25	0
284	24	7.04	0.00596	0.98000	30	0
285	24	13.80	0.47757	—	4	0
286	24	13.80	0.20666	—	6	0
287	24	13.80	0.11052	0.76095	8	0
288	24	13.80	0.07344	0.86948	10	0
289	24	13.80	0.05156	0.90768	12	0
290	24	13.80	0.03360	0.94766	15	0
291	24	13.80	0.02110	0.96817	20	0
292	24	13.80	0.01546	0.97610	25	0
293	24	13.80	0.01184	0.97513	30	0
294	24	24.90	0.79310	—	4	0
295	24	24.90	0.38855	—	6	0
296	24	24.90	0.22476	0.57961	8	0
297	24	24.90	0.14062	0.77402	10	0
298	24	24.90	0.09778	0.84622	12	0
299	24	24.90	0.06438	0.90804	15	0
300	24	24.90	0.03892	0.94819	20	0
301	24	24.90	0.02824	0.96387	25	0
302	24	24.90	0.02203	0.97500	30	0
303	24	49.20	0.73163	—	6	0
304	24	49.20	0.45840	0.27440	8	0
305	24	49.20	0.29780	0.55602	10	0
306	24	49.20	0.20384	0.70715	12	0
307	24	49.20	0.13566	0.82365	15	0
308	24	49.20	0.08054	0.90966	20	0
309	24	49.20	0.05855	0.93455	25	0
310	24	49.20	0.04540	0.94539	30	0
311	24	85.40	0.97872	—	6	0
312	24	85.40	0.72654	0.06603	8	0
313	24	85.40	0.52608	0.29875	10	0
314	24	85.40	0.37704	0.50430	12	0
315	24	85.40	0.25248	0.69341	15	0
316	24	85.40	0.14850	0.83155	20	0
317	24	85.40	0.10410	0.88987	25	0
318	24	85.40	0.08232	0.91084	30	0
319	26	3.55	0.23224	—	3	0
320	26	3.55	0.11327	—	4	0
321	26	3.55	0.04987	—	6	0
322	26	3.55	0.02745	0.81637	8	0
323	26	3.55	0.01818	0.96713	10	0
324	26	3.55	0.01205	0.96796	12	0
325	26	3.55	0.00854	0.97946	15	0
326	26	3.55	0.00553	0.99453	20	0
327	26	3.55	0.00388	0.99467	25	0
328	26	3.55	0.00295	0.99999	30	0
329	26	3.55	—	0.91032	6	1
330	26	3.55	—	0.92594	8	1
331	26	3.55	—	0.94591	10	1
332	26	3.55	—	0.95197	12	1
333	26	7.04	0.23452	—	4	0
334	26	7.04	0.10414	—	6	0
335	26	7.04	0.05678	0.75662	8	0
336	26	7.04	0.03612	0.93959	10	0
337	26	7.04	0.02490	0.98146	12	0
338	26	7.04	0.01769	0.98300	15	0
339	26	7.04	0.01040	0.98700	20	0
340	26	7.04	0.00746	0.99200	25	0
341	26	7.04	0.00599	0.99500	30	0
342	26	7.04	—	0.86684	6	1
343	26	7.04	—	0.90022	8	1
344	26	7.04	—	0.93265	10	1
345	26	7.04	—	0.95637	12	1
346	26	13.80	0.48080	—	4	0
347	26	13.80	0.20940	—	6	0

No.	$Z_{substrate}$	Mass thickness (μg cm^{-2})	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
348	26	13.80	0.11394	0.57793	8	0
349	26	13.80	0.07512	0.86758	10	0
350	26	13.80	0.05282	0.94376	12	0
351	26	13.80	0.03412	0.93564	15	0
352	26	13.80	0.02091	0.94043	20	0
353	26	13.80	0.01563	0.97845	25	0
354	26	13.80	0.01180	0.99999	30	0
355	26	13.80	—	0.77222	6	1
356	26	13.80	—	0.84891	8	1
357	26	13.80	—	0.88585	10	1
358	26	13.80	—	0.91239	12	1
359	26	24.90	0.78920	—	4	0
360	26	24.90	0.39604	—	6	0
361	26	24.90	0.22558	0.34707	8	0
362	26	24.90	0.14407	0.73640	10	0
363	26	24.90	0.09994	0.87865	12	0
364	26	24.90	0.06538	0.89956	15	0
365	26	24.90	0.04013	0.94004	20	0
366	26	24.90	0.02887	0.96704	25	0
367	26	24.90	0.02248	0.99999	30	0
368	26	24.90	—	0.58730	6	1
369	26	24.90	—	0.74152	8	1
370	26	24.90	—	0.80390	10	1
371	26	24.90	—	0.84390	12	1
372	26	49.20	0.73609	—	6	0
373	26	49.20	0.45993	0.09354	8	0
374	26	49.20	0.30140	0.49089	10	0
375	26	49.20	0.20834	0.71368	12	0
376	26	49.20	0.13693	0.80922	15	0
377	26	49.20	0.08200	0.84567	20	0
378	26	49.20	0.05718	0.91370	25	0
379	26	49.20	0.04557	0.96844	30	0
380	26	49.20	—	0.29215	6	1
381	26	49.20	—	0.51745	8	1
382	26	49.20	—	0.64521	10	1
383	26	49.20	—	0.71490	12	1
384	26	85.40	0.97766	—	6	0
385	26	85.40	0.73840	—	8	0
386	26	85.40	0.52578	0.22388	10	0
387	26	85.40	0.38546	0.48346	12	0
388	26	85.40	0.25522	0.67988	15	0
389	26	85.40	0.15070	0.82080	20	0
390	26	85.40	0.10494	0.88315	25	0
391	26	85.40	0.08052	0.94174	30	0
392	26	85.40	—	0.06428	6	1
393	26	85.40	—	0.25603	8	1
394	26	85.40	—	0.41962	10	1
395	26	85.40	—	0.53518	12	1
396	28	3.55	0.23590	—	3	0
397	28	3.55	0.11695	—	4	0
398	28	3.55	0.04979	—	6	0
399	28	3.55	0.02819	—	8	0
400	28	3.55	0.01840	0.92428	10	0
401	28	3.55	0.01282	0.97480	12	0
402	28	3.55	0.00880	0.97550	15	0
403	28	3.55	0.00564	0.99660	20	0
404	28	3.55	0.00402	0.98270	25	0
405	28	3.55	0.00304	0.99900	30	0
406	28	3.55	—	0.86817	4	1
407	28	3.55	—	0.93934	6	1
408	28	3.55	—	0.95785	8	1
409	28	3.55	—	0.96660	10	1
410	28	3.55	—	0.97370	12	1
411	28	3.55	—	0.98040	15	1
412	28	7.04	0.24013	—	4	0
413	28	7.04	0.10480	—	6	0
414	28	7.04	0.05750	—	8	0
415	28	7.04	0.03666	0.86015	10	0

No.	$Z_{substrate}$	Mass thickness ($\mu g\ cm^{-2}$)	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
416	28	7.04	0.02518	0.94880	12	0
417	28	7.04	0.01764	0.96600	15	0
418	28	7.04	0.01070	0.97000	20	0
419	28	7.04	0.00759	0.97730	25	0
420	28	7.04	0.00612	0.99270	30	0
421	28	7.04	—	0.74791	4	1
422	28	7.04	—	0.89227	6	1
423	28	7.04	—	0.91895	8	1
424	28	7.04	—	0.92649	10	1
425	28	7.04	—	0.94880	12	1
426	28	7.04	—	0.95410	15	1
427	28	13.80	0.48310	—	4	0
428	28	13.80	0.21244	—	6	0
429	28	13.80	0.11610	—	8	0
430	28	13.80	0.07686	0.78162	10	0
431	28	13.80	0.05334	0.90020	12	0
432	28	13.80	0.03528	0.91880	15	0
433	28	13.80	0.02181	0.94820	20	0
434	28	13.80	0.01605	0.96490	25	0
435	28	13.80	0.01227	0.97150	30	0
436	28	13.80	—	0.60489	4	1
437	28	13.80	—	0.84022	6	1
438	28	13.80	—	0.90192	8	1
439	28	13.80	—	0.91392	10	1
440	28	13.80	—	0.94820	12	1
441	28	13.80	—	0.95410	15	1
442	28	24.90	0.80592	—	4	0
443	28	24.90	0.39630	—	6	0
444	28	24.90	0.23103	—	8	0
445	28	24.90	0.14670	0.62058	10	0
446	28	24.90	0.10170	0.80860	12	0
447	28	24.90	0.06760	0.89560	15	0
448	28	24.90	0.04143	0.93440	20	0
449	28	24.90	0.02948	0.95580	25	0
450	28	24.90	0.02290	0.96000	30	0
451	28	24.90	—	0.32447	4	1
452	28	24.90	—	0.67740	6	1
453	28	24.90	—	0.81946	8	1
454	28	24.90	—	0.88660	10	1
455	28	24.90	—	0.90110	12	1
456	28	24.90	—	0.92350	15	1
457	28	49.20	0.73952	—	6	0
458	28	49.20	0.46307	—	8	0
459	28	49.20	0.30655	0.32144	10	0
460	28	49.20	0.21086	0.62640	12	0
461	28	49.20	0.14090	0.80200	15	0
462	28	49.20	0.08432	0.89350	20	0
463	28	49.20	0.06113	0.92550	25	0
464	28	49.20	0.04698	0.93980	30	0
465	28	49.20	—	0.04517	4	1
466	28	49.20	—	0.35622	6	1
467	28	49.20	—	0.61198	8	1
468	28	49.20	—	0.73603	10	1
469	28	49.20	—	0.80170	12	1
470	28	49.20	—	0.85210	15	1
471	28	85.40	0.98039	—	6	0
472	28	85.40	0.73590	—	8	0
473	28	85.40	0.53036	—	10	0
474	28	85.40	0.38626	0.38510	12	0
475	28	85.40	0.26136	0.64500	15	0
476	28	85.40	0.15410	0.82150	20	0
477	28	85.40	0.10718	0.87100	25	0
478	28	85.40	0.08208	0.90920	30	0
479	28	85.40	—	0.08446	6	1
480	28	85.40	—	0.32169	8	1
481	28	85.40	—	0.51495	10	1
482	28	85.40	—	0.64270	12	1
483	28	85.40	—	0.75390	15	1

No.	$Z_{substrate}$	Mass thickness ($\mu g\ cm^{-2}$)	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
484	29	3.55	0.23640	—	3	0
485	29	3.55	0.11740	—	4	0
486	29	3.55	0.05043	—	6	0
487	29	3.55	0.02920	—	8	0
488	29	3.55	0.01890	—	10	0
489	29	3.55	0.01286	0.94878	12	0
490	29	3.55	0.00884	0.97301	15	0
491	29	3.55	0.00565	0.98319	20	0
492	29	3.55	0.00405	0.99000	25	0
493	29	3.55	0.00311	0.99617	30	0
494	29	3.55	—	0.85512	4	1
495	29	3.55	—	0.93448	6	1
496	29	3.55	—	0.97200	8	1
497	29	3.55	—	0.95705	10	1
498	29	3.55	—	0.97310	12	1
499	29	3.55	—	0.97420	15	1
500	29	3.55	—	0.98663	20	1
501	29	3.55	—	0.99227	25	1
502	29	3.55	—	0.97592	30	1
503	29	7.04	0.24048	—	4	0
504	29	7.04	0.10579	—	6	0
505	29	7.04	0.05826	—	8	0
506	29	7.04	0.03732	—	10	0
507	29	7.04	0.02594	0.92677	12	0
508	29	7.04	0.01823	0.96248	15	0
509	29	7.04	0.01105	0.95736	20	0
510	29	7.04	0.00784	0.97979	25	0
511	29	7.04	0.00615	0.99000	30	0
512	29	7.04	—	0.74566	4	1
513	29	7.04	—	0.89242	6	1
514	29	7.04	—	0.94333	8	1
515	29	7.04	—	0.93681	10	1
516	29	7.04	—	0.95592	12	1
517	29	7.04	—	0.95662	15	1
518	29	7.04	—	0.98675	20	1
519	29	7.04	—	0.98785	25	1
520	29	7.04	—	0.99244	30	1
521	29	13.80	0.48384	—	4	0
522	29	13.80	0.21368	—	6	0
523	29	13.80	0.11748	—	8	0
524	29	13.80	0.07694	—	10	0
525	29	13.80	0.05312	0.92344	12	0
526	29	13.80	0.03740	0.93486	15	0
527	29	13.80	0.02196	0.93735	20	0
528	29	13.80	0.01628	0.98826	25	0
529	29	13.80	0.01235	0.99999	30	0
530	29	13.80	—	0.57197	4	1
531	29	13.80	—	0.80859	6	1
532	29	13.80	—	0.88203	8	1
533	29	13.80	—	0.90673	10	1
534	29	13.80	—	0.93856	12	1
535	29	13.80	—	0.94743	15	1
536	29	13.80	—	0.95955	20	1
537	29	13.80	—	0.95420	25	1
538	29	13.80	—	0.96708	30	1
539	29	24.90	0.80070	—	4	0
540	29	24.90	0.39731	—	6	0
541	29	24.90	0.23322	—	8	0
542	29	24.90	0.14783	—	10	0
543	29	24.90	0.10296	0.80334	12	0
544	29	24.90	0.06939	0.88389	15	0
545	29	24.90	0.04185	0.94048	20	0
546	29	24.90	0.02993	0.97383	25	0
547	29	24.90	0.02319	0.99999	30	0
548	29	24.90	—	0.31578	4	1
549	29	24.90	—	0.65147	6	1
550	29	24.90	—	0.78942	8	1
551	29	24.90	—	0.85093	10	1

No.	$Z_{substrate}$	Mass thickness ($\mu g\ cm^{-2}$)	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
552	29	24.90	—	0.89602	12	1
553	29	24.90	—	0.91347	15	1
554	29	24.90	—	0.95331	20	1
555	29	24.90	—	0.95017	25	1
556	29	24.90	—	0.95927	30	1
557	29	49.20	0.74348	—	6	0
558	29	49.20	0.46362	—	8	0
559	29	49.20	0.30638	—	10	0
560	29	49.20	0.21122	0.58060	12	0
561	29	49.20	0.14150	0.77922	15	0
562	29	49.20	0.08468	0.88183	20	0
563	29	49.20	0.06197	0.93446	25	0
564	29	49.20	0.04740	0.97656	30	0
565	29	49.20	—	0.03806	4	1
566	29	49.20	—	0.31838	6	1
567	29	49.20	—	0.56396	8	1
568	29	49.20	—	0.69030	10	1
569	29	49.20	—	0.77435	12	1
570	29	49.20	—	0.82359	15	1
571	29	49.20	—	0.87402	20	1
572	29	49.20	—	0.90751	25	1
573	29	49.20	—	0.90851	30	1
574	29	85.40	0.98100	—	6	0
575	29	85.40	0.74983	—	8	0
576	29	85.40	0.53302	—	10	0
577	29	85.40	0.38625	0.34329	12	0
578	29	85.40	0.27614	0.63040	15	0
579	29	85.40	0.15524	0.80689	20	0
580	29	85.40	0.10884	0.88276	25	0
581	29	85.40	0.08657	0.95664	30	0
582	29	85.40	—	0.07770	6	1
583	29	85.40	—	0.29645	8	1
584	29	85.40	—	0.48197	10	1
585	29	85.40	—	0.62005	12	1
586	29	85.40	—	0.72796	15	1
587	29	85.40	—	0.82260	20	1
588	29	85.40	—	0.85762	25	1
589	29	85.40	—	0.85740	30	1
590	32	3.55	0.24210	—	3	1
591	32	3.55	0.12064	0.87360	4	1
592	32	3.55	0.05189	0.95721	6	1
593	32	3.55	0.02891	0.96297	8	1
594	32	3.55	0.01928	0.98982	10	1
595	32	3.55	0.01333	0.98420	12	1
596	32	3.55	0.00916	0.99910	15	1
597	32	3.55	0.00587	0.99999	20	1
598	32	3.55	0.00414	0.99421	25	1
599	32	3.55	0.00308	0.99978	30	1
600	32	3.55	—	1.01977	15	0
601	32	3.55	—	1.00561	20	0
602	32	3.55	—	1.00261	25	0
603	32	3.55	—	1.01795	30	0
604	32	7.04	0.24552	0.76802	4	1
605	32	7.04	0.10918	0.91707	6	1
606	32	7.04	0.06004	0.93214	8	1
607	32	7.04	0.03856	0.97758	10	1
608	32	7.04	0.02658	0.97285	12	1
609	32	7.04	0.01825	0.99290	15	1
610	32	7.04	0.01149	0.99821	20	1
611	32	7.04	0.00813	0.99106	25	1
612	32	7.04	0.00618	0.99897	30	1
613	32	7.04	—	1.00244	15	0
614	32	7.04	—	0.99942	20	0
615	32	7.04	—	1.01833	25	0
616	32	7.04	—	1.01517	30	0
617	32	13.80	0.49236	0.56967	4	1
618	32	13.80	0.21920	0.82128	6	1
619	32	13.80	0.12086	0.87491	8	1

No.	$Z_{substrate}$	Mass thickness ($\mu g\ cm^{-2}$)	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
620	32	13.80	0.07906	0.93829	10	1
621	32	13.80	0.05468	0.94851	12	1
622	32	13.80	0.03616	0.97775	15	1
623	32	13.80	0.02227	0.98206	20	1
624	32	13.80	0.01656	0.99394	25	1
625	32	13.80	0.01259	0.99999	30	1
626	32	13.80	—	0.96794	15	0
627	32	13.80	—	0.98933	20	0
628	32	13.80	—	0.99346	25	0
629	32	13.80	—	1.01233	30	0
630	32	24.90	0.80986	0.29506	4	1
631	32	24.90	0.41186	0.65619	6	1
632	32	24.90	0.23620	0.79279	8	1
633	32	24.90	0.14986	0.87784	10	1
634	32	24.90	0.10544	0.90865	12	1
635	32	24.90	0.07081	0.95099	15	1
636	32	24.90	0.04226	0.96803	20	1
637	32	24.90	0.03024	0.98236	25	1
638	32	24.90	0.02372	0.98582	30	1
639	32	24.90	—	0.90592	15	0
640	32	24.90	—	0.96277	20	0
641	32	24.90	—	0.99311	25	0
642	32	24.90	—	0.99788	30	0
643	32	49.20	0.74887	0.32890	6	1
644	32	49.20	0.47498	0.57985	8	1
645	32	49.20	0.31592	0.72741	10	1
646	32	49.20	0.22024	0.80730	12	1
647	32	49.20	0.14558	0.89495	15	1
648	32	49.20	0.08638	0.93358	20	1
649	32	49.20	0.06162	0.95548	25	1
650	32	49.20	0.04865	0.95769	30	1
651	32	49.20	—	0.76563	15	0
652	32	49.20	—	0.91273	20	0
653	32	49.20	—	0.95254	25	0
654	32	49.20	—	0.97338	30	0
655	32	85.40	0.97568	0.07653	6	1
656	32	85.40	0.74624	0.30684	8	1
657	32	85.40	0.54814	0.51240	10	1
658	32	85.40	0.40134	0.64701	12	1
659	32	85.40	0.28466	0.78317	15	1
660	32	85.40	0.15866	0.87321	20	1
661	32	85.40	0.11895	0.91821	25	1
662	32	85.40	0.08824	0.92802	30	1
663	32	85.40	—	0.56032	15	0
664	32	85.40	—	0.82461	20	0
665	32	85.40	—	0.90512	25	0
666	32	85.40	—	0.93941	30	0
667	40	3.55	0.25204	—	3	1
668	40	3.55	0.12324	0.76180	4	1
669	40	3.55	0.05254	0.87800	6	1
670	40	3.55	0.03058	0.88790	8	1
671	40	3.55	0.01956	0.95450	10	1
672	40	3.55	0.01366	0.95380	12	1
673	40	3.55	0.00970	0.97620	15	1
674	40	3.55	0.00629	0.98440	20	1
675	40	3.55	0.00444	0.99230	25	1
676	40	3.55	0.00336	0.99610	30	1
677	40	7.04	0.24800	0.62940	4	1
678	40	7.04	0.11136	0.81840	6	1
679	40	7.04	0.06148	0.87600	8	1
680	40	7.04	0.03950	0.92750	10	1
681	40	7.04	0.02784	0.93650	12	1
682	40	7.04	0.01941	0.94980	15	1
683	40	7.04	0.01194	0.96760	20	1
684	40	7.04	0.00865	0.98010	25	1
685	40	7.04	0.00683	0.97570	30	1
686	40	13.80	0.49426	0.41500	4	1
687	40	13.80	0.22303	0.71250	6	1

No.	$Z_{substrate}$	Mass thickness ($\mu g\ cm^{-2}$)	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
688	40	13.80	0.12316	0.80580	8	1
689	40	13.80	0.08308	0.87390	10	1
690	40	13.80	0.05782	0.88920	12	1
691	40	13.80	0.03933	0.92260	15	1
692	40	13.80	0.02430	0.95220	20	1
693	40	13.80	0.01811	0.95710	25	1
694	40	13.80	0.01375	0.95400	30	1
695	40	24.90	0.80654	0.16580	4	1
696	40	24.90	0.41912	0.52560	6	1
697	40	24.90	0.24331	0.69180	8	1
698	40	24.90	0.15909	0.79780	10	1
699	40	24.90	0.11094	0.82590	12	1
700	40	24.90	0.07749	0.87420	15	1
701	40	24.90	0.04572	0.89720	20	1
702	40	24.90	0.03302	0.90640	25	1
703	40	24.90	0.02580	0.91350	30	1
704	40	49.20	0.75257	0.21960	6	1
705	40	49.20	0.48325	0.45830	8	1
706	40	49.20	0.32296	0.60770	10	1
707	40	49.20	0.22848	0.68550	12	1
708	40	49.20	0.15386	0.75850	15	1
709	40	49.20	0.09228	0.81150	20	1
710	40	49.20	0.06784	0.83680	25	1
711	40	49.20	0.05287	0.84970	30	1
712	40	85.40	0.98987	0.03500	6	1
713	40	85.40	0.78718	0.19910	8	1
714	40	85.40	0.56787	0.37090	10	1
715	40	85.40	0.42383	0.48830	12	1
716	40	85.40	0.29511	0.60050	15	1
717	40	85.40	0.16915	0.69700	20	1
718	40	85.40	0.12714	0.72960	25	1
719	40	85.40	0.09498	0.74150	30	1
720	42	3.55	0.26392	—	3	1
721	42	3.55	0.12690	0.75760	4	1
722	42	3.55	0.05420	0.89775	6	1
723	42	3.55	0.03101	0.95313	8	1
724	42	3.55	0.02060	0.96561	10	1
725	42	3.55	0.01446	0.97440	12	1
726	42	3.55	0.00985	0.98619	15	1
727	42	3.55	0.00638	0.99148	20	1
728	42	3.55	0.00455	0.99471	25	1
729	42	3.55	0.00347	0.98904	30	1
730	42	7.04	0.25158	0.59394	4	1
731	42	7.04	0.11266	0.81617	6	1
732	42	7.04	0.06234	0.91305	8	1
733	42	7.04	0.04041	0.93440	10	1
734	42	7.04	0.02909	0.95384	12	1
735	42	7.04	0.01957	0.97092	15	1
736	42	7.04	0.01202	0.99236	20	1
737	42	7.04	0.00851	0.98509	25	1
738	42	7.04	0.00685	0.98915	30	1
739	42	13.80	0.49466	0.39323	4	1
740	42	13.80	0.23088	0.73573	6	1
741	42	13.80	0.12564	0.86316	8	1
742	42	13.80	0.08322	0.90646	10	1
743	42	13.80	0.05820	0.92300	12	1
744	42	13.80	0.04025	0.94704	15	1
745	42	13.80	0.02402	0.96127	20	1
746	42	13.80	0.01794	0.96348	25	1
747	42	13.80	0.01370	0.96221	30	1
748	42	24.90	0.80792	0.13587	4	1
749	42	24.90	0.41974	0.53560	6	1
750	42	24.90	0.24925	0.73172	8	1
751	42	24.90	0.16034	0.81705	10	1
752	42	24.90	0.11267	0.86367	12	1
753	42	24.90	0.07780	0.90203	15	1
754	42	24.90	0.04623	0.92913	20	1
755	42	24.90	0.03316	0.93528	25	1

No.	$Z_{substrate}$	Mass thickness ($\mu g\ cm^{-2}$)	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
756	42	24.90	0.02517	0.93495	30	1
757	42	49.20	0.75868	0.22365	6	1
758	42	49.20	0.48500	0.49811	8	1
759	42	49.20	0.32780	0.64294	10	1
760	42	49.20	0.22668	0.72806	12	1
761	42	49.20	0.15262	0.79890	15	1
762	42	49.20	0.09422	0.85791	20	1
763	42	49.20	0.06801	0.87075	25	1
764	42	49.20	0.05279	0.87671	30	1
765	42	85.40	0.99469	—	6	1
766	42	85.40	0.79137	0.22597	8	1
767	42	85.40	0.56563	0.40598	10	1
768	42	85.40	0.42250	0.53971	12	1
769	42	85.40	0.29671	0.65725	15	1
770	42	85.40	0.17396	0.75281	20	1
771	42	85.40	0.12771	0.79795	25	1
772	42	85.40	0.09543	0.80574	30	1
773	44	3.55	0.27436	—	3	1
774	44	3.55	0.13065	—	4	1
775	44	3.55	0.05629	—	6	1
776	44	3.55	0.03168	—	8	1
777	44	3.55	0.02068	—	10	1
778	44	3.55	0.01459	—	12	1
779	44	3.55	0.00995	—	15	1
780	44	3.55	0.00637	—	20	1
781	44	3.55	0.00455	—	25	1
782	44	3.55	0.00345	—	30	1
783	44	7.04	0.25913	—	4	1
784	44	7.04	0.11623	—	6	1
785	44	7.04	0.06474	—	8	1
786	44	7.04	0.04116	—	10	1
787	44	7.04	0.03025	—	12	1
788	44	7.04	0.02032	—	15	1
789	44	7.04	0.01225	—	20	1
790	44	7.04	0.00876	—	25	1
791	44	7.04	0.00695	—	30	1
792	44	13.80	0.50892	—	4	1
793	44	13.80	0.23705	—	6	1
794	44	13.80	0.12598	—	8	1
795	44	13.80	0.08416	—	10	1
796	44	13.80	0.06028	—	12	1
797	44	13.80	0.03999	—	15	1
798	44	13.80	0.02468	—	20	1
799	44	13.80	0.01817	—	25	1
800	44	13.80	0.01383	—	30	1
801	44	24.90	0.81956	—	4	1
802	44	24.90	0.43152	—	6	1
803	44	24.90	0.25087	—	8	1
804	44	24.90	0.16510	—	10	1
805	44	24.90	0.11256	—	12	1
806	44	24.90	0.07817	—	15	1
807	44	24.90	0.04588	—	20	1
808	44	24.90	0.03277	—	25	1
809	44	24.90	0.02572	—	30	1
810	44	49.20	0.77019	—	6	1
811	44	49.20	0.48798	—	8	1
812	44	49.20	0.32870	—	10	1
813	44	49.20	0.23565	—	12	1
814	44	49.20	0.15851	—	15	1
815	44	49.20	0.09665	—	20	1
816	44	49.20	0.06816	—	25	1
817	44	49.20	0.05323	—	30	1
818	44	85.40	0.98348	—	6	1
819	44	85.40	0.79878	—	8	1
820	44	85.40	0.57168	—	10	1
821	44	85.40	0.42853	—	12	1
822	44	85.40	0.30092	—	15	1
823	44	85.40	0.18039	—	20	1

No.	$Z_{substrate}$	Mass thickness ($\mu g\ cm^{-2}$)	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
824	44	85.40	0.12821	—	25	1
825	44	85.40	0.09617	—	30	1
826	46	3.55	0.27122	—	3	1
827	46	3.55	0.12934	0.69041	4	1
828	46	3.55	0.05583	0.88064	6	1
829	46	3.55	0.03129	0.92621	8	1
830	46	3.55	0.02068	0.96125	10	1
831	46	3.55	0.01420	0.96319	12	1
832	46	3.55	0.00983	0.97579	15	1
833	46	3.55	0.00620	0.96861	20	1
834	46	3.55	0.00432	0.97407	25	1
835	46	3.55	0.00335	0.98934	30	1
836	46	7.04	0.25133	0.51512	4	1
837	46	7.04	0.11336	0.79778	6	1
838	46	7.04	0.06332	0.87014	8	1
839	46	7.04	0.04107	0.93024	10	1
840	46	7.04	0.02929	0.93975	12	1
841	46	7.04	0.01989	0.97483	15	1
842	46	7.04	0.01196	0.97966	20	1
843	46	7.04	0.00842	0.97629	25	1
844	46	7.04	0.00676	0.99365	30	1
845	46	13.80	0.50422	0.25224	4	1
846	46	13.80	0.23558	0.70253	6	1
847	46	13.80	0.12660	0.82163	8	1
848	46	13.80	0.08485	0.90280	10	1
849	46	13.80	0.05991	0.91574	12	1
850	46	13.80	0.04103	0.93687	15	1
851	46	13.80	0.02437	0.94595	20	1
852	46	13.80	0.01800	0.95739	25	1
853	46	13.80	0.01384	0.97235	30	1
854	46	24.90	0.81642	0.05594	4	1
855	46	24.90	0.42516	0.50095	6	1
856	46	24.90	0.24858	0.71124	8	1
857	46	24.90	0.16303	0.83757	10	1
858	46	24.90	0.11492	0.87670	12	1
859	46	24.90	0.07775	0.91406	15	1
860	46	24.90	0.04543	0.92447	20	1
861	46	24.90	0.03365	0.94507	25	1
862	46	24.90	0.02555	0.96059	30	1
863	46	49.20	0.75683	0.18682	6	1
864	46	49.20	0.49126	0.48034	8	1
865	46	49.20	0.33152	0.67516	10	1
866	46	49.20	0.23352	0.74883	12	1
867	46	49.20	0.15600	0.83430	15	1
868	46	49.20	0.09696	0.87311	20	1
869	46	49.20	0.06876	0.90872	25	1
870	46	49.20	0.05318	0.93068	30	1
871	46	85.40	0.98271	—	6	1
872	46	85.40	0.78414	0.20242	8	1
873	46	85.40	0.56459	0.41761	10	1
874	46	85.40	0.42340	0.56498	12	1
875	46	85.40	0.30022	0.70116	15	1
876	46	85.40	0.18183	0.79555	20	1
877	46	85.40	0.12968	0.83963	25	1
878	46	85.40	0.09742	0.85919	30	1
879	50	3.55	0.26654	—	3	1
880	50	3.55	0.12956	—	4	1
881	50	3.55	0.05588	0.82236	6	1
882	50	3.55	0.03152	0.90555	8	1
883	50	3.55	0.02059	0.92986	10	1
884	50	3.55	0.01471	0.93743	12	1
885	50	3.55	0.01031	0.95167	15	1
886	50	3.55	0.00660	0.96578	20	1
887	50	3.55	0.00464	0.97362	25	1
888	50	3.55	0.00341	0.98990	30	1
889	50	7.04	0.25584	—	4	1
890	50	7.04	0.11594	0.74884	6	1
891	50	7.04	0.06472	0.85336	8	1

No.	$Z_{substrate}$	Mass thickness ($\mu g\ cm^{-2}$)	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
892	50	7.04	0.04126	0.88861	10	1
893	50	7.04	0.02969	0.92168	12	1
894	50	7.04	0.02057	0.94272	15	1
895	50	7.04	0.01260	0.95546	20	1
896	50	7.04	0.00907	0.96824	25	1
897	50	7.04	0.00698	0.98159	30	1
898	50	13.80	0.50416	—	4	1
899	50	13.80	0.23708	0.59419	6	1
900	50	13.80	0.12804	0.80121	8	1
901	50	13.80	0.08573	0.83904	10	1
902	50	13.80	0.06008	0.89992	12	1
903	50	13.80	0.04124	0.92400	15	1
904	50	13.80	0.02447	0.94523	20	1
905	50	13.80	0.01838	0.95999	25	1
906	50	13.80	0.01414	0.97494	30	1
907	50	24.90	0.81764	—	4	1
908	50	24.90	0.43128	0.40265	6	1
909	50	24.90	0.25004	0.66827	8	1
910	50	24.90	0.16597	0.78642	10	1
911	50	24.90	0.11766	0.86025	12	1
912	50	24.90	0.07947	0.89165	15	1
913	50	24.90	0.04667	0.92186	20	1
914	50	24.90	0.03366	0.95089	25	1
915	50	24.90	0.02755	0.96763	30	1
916	50	49.20	0.75981	0.11597	6	1
917	50	49.20	0.49385	0.42023	8	1
918	50	49.20	0.33888	0.59281	10	1
919	50	49.20	0.23662	0.71910	12	1
920	50	49.20	0.16276	0.79539	15	1
921	50	49.20	0.09747	0.87948	20	1
922	50	49.20	0.06943	0.91038	25	1
923	50	49.20	0.05405	0.93791	30	1
924	50	85.40	0.98791	0.01060	6	1
925	50	85.40	0.79347	0.17341	8	1
926	50	85.40	0.57306	0.38589	10	1
927	50	85.40	0.43071	0.55331	12	1
928	50	85.40	0.30611	0.69927	15	1
929	50	85.40	0.18653	0.81229	20	1
930	50	85.40	0.13216	0.87045	25	1
931	50	85.40	0.10233	0.90615	30	1
932	72	3.55	0.27510	—	3	2
933	72	3.55	0.13310	—	4	2
934	72	3.55	0.05782	—	6	2
935	72	3.55	0.03336	—	8	2
936	72	3.55	0.02213	—	10	2
937	72	3.55	0.01582	—	12	2
938	72	3.55	0.01075	—	15	2
939	72	3.55	0.00686	—	20	2
940	72	3.55	0.00485	—	25	2
941	72	3.55	0.00362	—	30	2
942	72	7.04	0.27060	—	4	2
943	72	7.04	0.11973	—	6	2
944	72	7.04	0.06808	—	8	2
945	72	7.04	0.04408	—	10	2
946	72	7.04	0.03167	—	12	2
947	72	7.04	0.02159	—	15	2
948	72	7.04	0.01345	—	20	2
949	72	7.04	0.00959	—	25	2
950	72	7.04	0.00722	—	30	2
951	72	13.80	0.51252	—	4	2
952	72	13.80	0.24728	—	6	2
953	72	13.80	0.13910	—	8	2
954	72	13.80	0.09128	—	10	2
955	72	13.80	0.06482	—	12	2
956	72	13.80	0.04409	—	15	2
957	72	13.80	0.02653	—	20	2
958	72	13.80	0.01977	—	25	2
959	72	13.80	0.01512	—	30	2

No.	$Z_{substrate}$	Mass thickness ($\mu g\ cm^{-2}$)	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
960	72	24.90	0.83198	—	4	2
961	72	24.90	0.44830	—	6	2
962	72	24.90	0.26790	—	8	2
963	72	24.90	0.17643	—	10	2
964	72	24.90	0.12531	—	12	2
965	72	24.90	0.08516	—	15	2
966	72	24.90	0.04988	—	20	2
967	72	24.90	0.03607	—	25	2
968	72	24.90	0.02819	—	30	2
969	72	49.20	0.77723	—	6	2
970	72	49.20	0.51799	—	8	2
971	72	49.20	0.35418	—	10	2
972	72	49.20	0.25246	—	12	2
973	72	49.20	0.17611	—	15	2
974	72	49.20	0.10554	—	20	2
975	72	49.20	0.07483	—	25	2
976	72	49.20	0.05818	—	30	2
977	72	85.40	0.98338	—	6	2
978	72	85.40	0.80270	—	8	2
979	72	85.40	0.59334	—	10	2
980	72	85.40	0.45116	—	12	2
981	72	85.40	0.32736	—	15	2
982	72	85.40	0.19971	—	20	2
983	72	85.40	0.14092	—	25	2
984	72	85.40	0.10991	—	30	2
985	74	3.55	0.27770	—	3	2
986	74	3.55	0.13818	0.83888	4	2
987	74	3.55	0.05859	0.91928	6	2
988	74	3.55	0.03448	0.95856	8	2
989	74	3.55	0.02208	0.97188	10	2
990	74	3.55	0.01600	0.97863	12	2
991	74	3.55	0.01080	0.99768	15	2
992	74	3.55	0.00686	1.00478	20	2
993	74	3.55	0.00485	0.99779	25	2
994	74	3.55	0.00374	0.99354	30	2
995	74	3.55	—	0.93353	12	1
996	74	3.55	—	0.96911	15	1
997	74	3.55	—	0.98804	20	1
998	74	3.55	—	0.98065	25	1
999	74	3.55	—	1.00204	30	1
1000	74	7.04	0.26158	0.71677	4	2
1001	74	7.04	0.12147	0.85968	6	2
1002	74	7.04	0.06837	0.92176	8	2
1003	74	7.04	0.04437	0.96127	10	2
1004	74	7.04	0.03213	0.96503	12	2
1005	74	7.04	0.02198	0.97252	15	2
1006	74	7.04	0.01334	0.97797	20	2
1007	74	7.04	0.00957	0.97127	25	2
1008	74	7.04	0.00746	0.94785	30	2
1009	74	7.04	—	0.88842	12	1
1010	74	7.04	—	0.96578	15	1
1011	74	7.04	—	0.98724	20	1
1012	74	7.04	—	0.97999	25	1
1013	74	7.04	—	1.00377	30	1
1014	74	13.80	0.51178	0.45738	4	2
1015	74	13.80	0.24758	0.74233	6	2
1016	74	13.80	0.13942	0.85120	8	2
1017	74	13.80	0.09058	0.90015	10	2
1018	74	13.80	0.06396	0.91240	12	2
1019	74	13.80	0.04454	0.92667	15	2
1020	74	13.80	0.02619	0.93300	20	2
1021	74	13.80	0.01957	0.91976	25	2
1022	74	13.80	0.01508	0.91406	30	2
1023	74	13.80	—	0.80056	12	1
1024	74	13.80	—	0.92794	15	1
1025	74	13.80	—	0.97413	20	1
1026	74	13.80	—	0.97793	25	1
1027	74	13.80	—	0.99211	30	1

No.	$Z_{substrate}$	Mass thickness (μg cm^{-2})	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
1028	74	24.90	0.81579	0.20594	4	2
1029	74	24.90	0.44546	0.56021	6	2
1030	74	24.90	0.26424	0.72687	8	2
1031	74	24.90	0.17422	0.81932	10	2
1032	74	24.90	0.12333	0.84299	12	2
1033	74	24.90	0.08399	0.87516	15	2
1034	74	24.90	0.04902	0.89553	20	2
1035	74	24.90	0.03564	0.88241	25	2
1036	74	24.90	0.02890	0.89058	30	2
1037	74	24.90	—	0.66753	12	1
1038	74	24.90	—	0.87677	15	1
1039	74	24.90	—	0.94722	20	1
1040	74	24.90	—	0.96684	25	1
1041	74	24.90	—	0.98918	30	1
1042	74	49.20	0.77260	0.24310	6	2
1043	74	49.20	0.51181	0.47747	8	2
1044	74	49.20	0.35923	0.61869	10	2
1045	74	49.20	0.25578	0.68521	12	2
1046	74	49.20	0.17934	0.74526	15	2
1047	74	49.20	0.10410	0.78880	20	2
1048	74	49.20	0.07483	0.79064	25	2
1049	74	49.20	0.05818	0.78084	30	2
1050	74	49.20	—	0.41900	12	1
1051	74	49.20	—	0.75840	15	1
1052	74	49.20	—	0.89708	20	1
1053	74	49.20	—	0.94181	25	1
1054	74	49.20	—	0.96860	30	1
1055	74	85.40	0.97928	0.04094	6	2
1056	74	85.40	0.79320	0.19832	8	2
1057	74	85.40	0.58398	0.36784	10	2
1058	74	85.40	0.45547	0.46943	12	2
1059	74	85.40	0.32513	0.56642	15	2
1060	74	85.40	0.19787	0.64344	20	2
1061	74	85.40	0.14145	0.66522	25	2
1062	74	85.40	0.10911	0.66965	30	2
1063	74	85.40	—	0.17018	12	1
1064	74	85.40	—	0.57438	15	1
1065	74	85.40	—	0.81220	20	1
1066	74	85.40	—	0.88889	25	1
1067	74	85.40	—	0.92729	30	1
1068	78	3.55	0.27216	—	3	2
1069	78	3.55	0.13914	—	4	2
1070	78	3.55	0.05871	—	6	2
1071	78	3.55	0.03410	—	8	2
1072	78	3.55	0.02268	—	10	2
1073	78	3.55	0.01609	—	12	2
1074	78	3.55	0.01113	—	15	2
1075	78	3.55	0.00697	—	20	2
1076	78	3.55	0.00502	—	25	2
1077	78	3.55	0.00383	—	30	2
1078	78	7.04	0.26509	—	4	2
1079	78	7.04	0.12267	—	6	2
1080	78	7.04	0.06866	—	8	2
1081	78	7.04	0.04499	—	10	2
1082	78	7.04	0.03245	—	12	2
1083	78	7.04	0.02215	—	15	2
1084	78	7.04	0.01353	—	20	2
1085	78	7.04	0.00979	—	25	2
1086	78	7.04	0.00759	—	30	2
1087	78	13.80	0.51778	—	4	2
1088	78	13.80	0.24770	—	6	2
1089	78	13.80	0.14008	—	8	2
1090	78	13.80	0.09246	—	10	2
1091	78	13.80	0.06515	—	12	2
1092	78	13.80	0.04445	—	15	2
1093	78	13.80	0.02669	—	20	2
1094	78	13.80	0.01999	—	25	2
1095	78	13.80	0.01547	—	30	2

No.	$Z_{substrate}$	Mass thickness ($\mu g\ cm^{-2}$)	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
1096	78	24.90	0.83290	—	4	2
1097	78	24.90	0.44936	—	6	2
1098	78	24.90	0.26587	—	8	2
1099	78	24.90	0.17827	—	10	2
1100	78	24.90	0.12688	—	12	2
1101	78	24.90	0.08658	—	15	2
1102	78	24.90	0.05152	—	20	2
1103	78	24.90	0.03695	—	25	2
1104	78	24.90	0.02864	—	30	2
1105	78	49.20	0.78130	—	6	2
1106	78	49.20	0.51946	—	8	2
1107	78	49.20	0.36380	—	10	2
1108	78	49.20	0.26161	—	12	2
1109	78	49.20	0.17734	—	15	2
1110	78	49.20	0.10651	—	20	2
1111	78	49.20	0.07611	—	25	2
1112	78	49.20	0.05836	—	30	2
1113	78	85.40	0.98166	—	6	2
1114	78	85.40	0.79338	—	8	2
1115	78	85.40	0.58898	—	10	2
1116	78	85.40	0.45892	—	12	2
1117	78	85.40	0.32829	—	15	2
1118	78	85.40	0.19913	—	20	2
1119	78	85.40	0.14283	—	25	2
1120	78	85.40	0.10989	—	30	2
1121	79	3.55	0.27688	—	3	2
1122	79	3.55	0.13914	0.80516	4	2
1123	79	3.55	0.05935	0.94024	6	2
1124	79	3.55	0.03414	0.98877	8	2
1125	79	3.55	0.02292	1.00272	10	2
1126	79	3.55	0.01616	0.99259	12	2
1127	79	3.55	0.01108	0.99331	15	2
1128	79	3.55	0.00704	1.00581	20	2
1129	79	3.55	0.00504	0.98497	25	2
1130	79	3.55	0.00379	0.99787	30	2
1131	79	3.55	—	0.91456	15	1
1132	79	3.55	—	0.99044	20	1
1133	79	3.55	—	0.98960	25	1
1134	79	3.55	—	1.00455	30	1
1135	79	7.04	0.26509	0.68384	4	2
1136	79	7.04	0.12283	0.85407	6	2
1137	79	7.04	0.06915	0.93866	8	2
1138	79	7.04	0.04581	0.94735	10	2
1139	79	7.04	0.03245	0.96770	12	2
1140	79	7.04	0.02215	0.96282	15	2
1141	79	7.04	0.01340	0.99125	20	2
1142	79	7.04	0.00979	0.96707	25	2
1143	79	7.04	0.00760	0.98649	30	2
1144	79	7.04	—	0.91106	15	1
1145	79	7.04	—	0.97840	20	1
1146	79	7.04	—	0.98593	25	1
1147	79	7.04	—	0.99691	30	1
1148	79	13.80	0.51400	0.43285	4	2
1149	79	13.80	0.24978	0.75303	6	2
1150	79	13.80	0.14099	0.88205	8	2
1151	79	13.80	0.09230	0.91696	10	2
1152	79	13.80	0.06478	0.93927	12	2
1153	79	13.80	0.04467	0.95280	15	2
1154	79	13.80	0.02689	0.97021	20	2
1155	79	13.80	0.02009	0.94365	25	2
1156	79	13.80	0.01554	0.95862	30	2
1157	79	13.80	—	0.87754	15	1
1158	79	13.80	—	0.96500	20	1
1159	79	13.80	—	0.97757	25	1
1160	79	13.80	—	0.99991	30	1
1161	79	24.90	0.82396	0.17062	4	2
1162	79	24.90	0.44922	0.57915	6	2
1163	79	24.90	0.26566	0.78082	8	2

No.	$Z_{substrate}$	Mass thickness ($\mu g\ cm^{-2}$)	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
1164	79	24.90	0.17975	0.85783	10	2
1165	79	24.90	0.12572	0.86525	12	2
1166	79	24.90	0.08578	0.91659	15	2
1167	79	24.90	0.05033	0.93643	20	2
1168	79	24.90	0.03626	0.91585	25	2
1169	79	24.90	0.02854	0.93679	30	2
1170	79	24.90	—	0.81161	15	1
1171	79	24.90	—	0.94061	20	1
1172	79	24.90	—	0.96398	25	1
1173	79	24.90	—	0.99351	30	1
1174	79	49.20	0.77628	0.23995	6	2
1175	79	49.20	0.51984	0.51384	8	2
1176	79	49.20	0.36265	0.66243	10	2
1177	79	49.20	0.25992	0.72299	12	2
1178	79	49.20	0.18200	0.79683	15	2
1179	79	49.20	0.10498	0.85078	20	2
1180	79	49.20	0.07617	0.83897	25	2
1181	79	49.20	0.05700	0.86510	30	2
1182	79	49.20	—	0.64187	15	1
1183	79	49.20	—	0.88481	20	1
1184	79	49.20	—	0.94215	25	1
1185	79	49.20	—	0.97066	30	1
1186	79	85.40	0.97780	0.04013	6	2
1187	79	85.40	0.79641	0.23740	8	2
1188	79	85.40	0.58660	0.42053	10	2
1189	79	85.40	0.45860	0.53788	12	2
1190	79	85.40	0.32861	0.65998	15	2
1191	79	85.40	0.19805	0.74521	20	2
1192	79	85.40	0.14259	0.76208	25	2
1193	79	85.40	0.11017	0.76851	30	2
1194	79	85.40	—	0.43504	15	1
1195	79	85.40	—	0.79330	20	1
1196	79	85.40	—	0.88851	25	1
1197	79	85.40	—	0.94852	30	1
1198	83	3.55	0.27697	—	3	2
1199	83	3.55	0.14542	0.69741	4	2
1200	83	3.55	0.05937	0.90320	6	2
1201	83	3.55	0.03488	0.94928	8	2
1202	83	3.55	0.02360	0.96350	10	2
1203	83	3.55	0.01666	0.97856	12	2
1204	83	3.55	0.01108	0.98195	15	2
1205	83	3.55	0.00703	0.98522	20	2
1206	83	3.55	0.00488	0.99811	25	2
1207	83	3.55	0.00387	0.99607	30	2
1208	83	3.55	—	0.93699	15	1
1209	83	3.55	—	0.96807	20	1
1210	83	3.55	—	0.99937	25	1
1211	83	3.55	—	0.98542	30	1
1212	83	7.04	0.27104	0.58641	4	2
1213	83	7.04	0.12345	0.85675	6	2
1214	83	7.04	0.07000	0.92134	8	2
1215	83	7.04	0.04543	0.94287	10	2
1216	83	7.04	0.03244	0.95824	12	2
1217	83	7.04	0.02242	0.95478	15	2
1218	83	7.04	0.01364	0.98135	20	2
1219	83	7.04	0.00975	0.99559	25	2
1220	83	7.04	0.00759	0.97883	30	2
1221	83	7.04	—	0.89982	15	1
1222	83	7.04	—	0.96399	20	1
1223	83	7.04	—	0.99001	25	1
1224	83	7.04	—	0.98620	30	1
1225	83	13.80	0.51922	0.34335	4	2
1226	83	13.80	0.25102	0.72360	6	2
1227	83	13.80	0.14138	0.86365	8	2
1228	83	13.80	0.09286	0.90252	10	2
1229	83	13.80	0.06551	0.92837	12	2
1230	83	13.80	0.04472	0.94910	15	2
1231	83	13.80	0.02703	0.95706	20	2

No.	$Z_{substrate}$	Mass thickness ($\mu g\ cm^{-2}$)	k (Al Kα)	k (substrate)	Accelerating voltage (kV)	Substrate line
1232	83	13.80	0.02004	0.97920	25	2
1233	83	13.80	0.01543	0.98110	30	2
1234	83	13.80	—	0.81189	15	1
1235	83	13.80	—	0.94424	20	1
1236	83	13.80	—	0.98917	25	1
1237	83	13.80	—	0.97723	30	1
1238	83	24.90	0.81964	0.12205	4	2
1239	83	24.90	0.45268	0.55337	6	2
1240	83	24.90	0.26908	0.74913	8	2
1241	83	24.90	0.18131	0.83141	10	2
1242	83	24.90	0.12864	0.87177	12	2
1243	83	24.90	0.08744	0.91376	15	2
1244	83	24.90	0.05188	0.93655	20	2
1245	83	24.90	0.03727	0.95159	25	2
1246	83	24.90	0.02886	0.94426	30	2
1247	83	24.90	—	0.70546	15	1
1248	83	24.90	—	0.91168	20	1
1249	83	24.90	—	0.96633	25	1
1250	83	24.90	—	0.98093	30	1
1251	83	49.20	0.77970	0.22253	6	2
1252	83	49.20	0.52052	0.50142	8	2
1253	83	49.20	0.36346	0.66204	10	2
1254	83	49.20	0.26178	0.74585	12	2
1255	83	49.20	0.17878	0.83010	15	2
1256	83	49.20	0.10473	0.86324	20	2
1257	83	49.20	0.07596	0.90133	25	2
1258	83	49.20	0.05678	0.90511	30	2
1259	83	49.20	—	0.47338	15	1
1260	83	49.20	—	0.83610	20	1
1261	83	49.20	—	0.94454	25	1
1262	83	49.20	—	0.95228	30	1
1263	83	85.40	0.98018	0.03430	6	2
1264	83	85.40	0.79616	0.23011	8	2
1265	83	85.40	0.58993	0.42431	10	2
1266	83	85.40	0.45492	0.56593	12	2
1267	83	85.40	0.33000	0.69521	15	2
1268	83	85.40	0.19964	0.77948	20	2
1269	83	85.40	0.14284	0.83194	25	2
1270	83	85.40	0.11014	0.84449	30	2
1271	83	85.40	—	0.21649	15	1
1272	83	85.40	—	0.73280	20	1
1273	83	85.40	—	0.88332	25	1
1274	83	85.40	—	0.92594	30	1