《电子探针显微分析仪校准规范》

试验报告

（征求意见稿）

**《电子探针显微分析仪校准规范》编写组**

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**《电子探针显微分析仪校准规范》试验报告**

**一、实验目的**

为了验证《电子探针显微分析仪校准规范》中校准方法的科学性和可操作性，以及规范中不确定度评定的合理性，选择有代表性厂家生产的电子探针显微分析仪进行试验，对长度测量示值误差，正交性误差，线性失真度，样品台重复性，定量分析示值误差、定量分析测量重复性六项计量特性的校准方法进行评价。

**二、实验方法**

（一）长度测量示值误差

聚焦清晰后采集图像，并记录相应的图像放大倍率，如图1所示。测量图像上X方向*M*（*M*≥5）个栅格周期结构的长度*D*（见图2），标准器X方向间距测量值*L*按照公式（1）进行计算：

（1）

式中：*L*—标准器间距测量值，nm；

*D*—*M*个栅格周期结构的长度，nm；

*M*—标准器间距测量值对应的周期数。

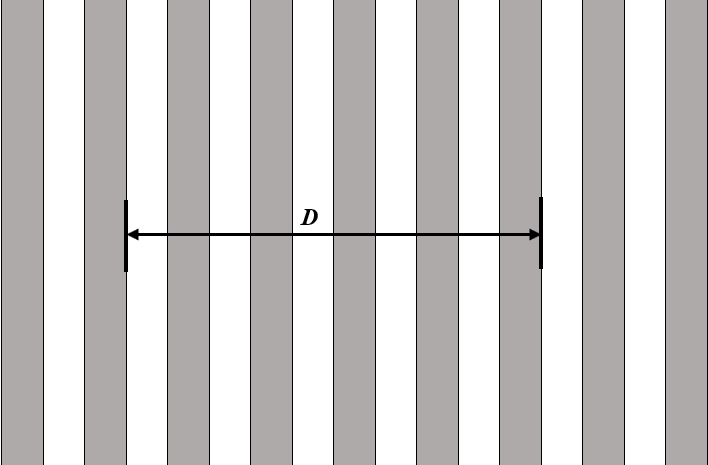


图1 标准物质X方向测长值校准示意图

重复测量6次，计算6次测量值的算术平均值，电子探针长度测量示值误差按照公式（2）进行计算：

（2）

式中：Δ*L* —电子探针长度测量示值误差，nm；

—标准器间距测量算术平均值，nm；

*L*s —标准器间距标准值，nm；

将样品台旋转90°，使栅格线条沿着图像水平方向，按照标准器X方向平均间距的测量方法测量标准器Y方向平均间距，计算Y方向长度测量示值误差。

（二）正交性误差

测量二维栅格图像上X方向、Y方向5个以上周期结构的夹角角度，重复测量3次，计算3次正交角度测量值的算术平均值。电子探针正交性误差按照公式（3）进行计算：

Δ*θ*=－*θs* （3）

式中：Δ*θ* —电子探针正交性误差，°；

—标准器正交角度测量算术平均值，°；

*θs* —标准器正交角度标准值，°。

（三）线性失真度

选取一个栅格，分别平移到屏幕的中心和四角，各获取一幅图像，并测量同一栅格在这5个位置上X方向、Y方向的宽度，分别为*X*0，*Y*0；*X*1，*Y* 1；*X*2，*Y* 2；*X*3，*Y* 3；*X*4，*Y* 4。该栅格在屏幕中心和四角5个位置上X方向、Y方向长度差分别为，，其中i=1，2，3，4。中的最大值为，中的最大值为。

X方向线性失真度按照公式（4）进行计算：

（4）

Y方向线性失真度按照公式（5）进行计算：

（5）

式中：*α*—电子探针X方向线性失真度，%；

—同一栅格在屏幕中心与四角的X方向长度差最大值，nm；

—栅格在屏幕中心X方向长度测得值，nm；

*β*—电子探针Y方向线性失真度，%；

—同一栅格在屏幕中心与四角的Y方向长度差最大值，nm；

—栅格在屏幕中心的Y方向长度测得值，nm。

（四）样品台重复性

将标准器上一个标记点移到屏幕的中心位置，消除齿轮间距并采集图像。将样品台分别在X方向和Y方向的相对位移移开5mm以上，消除齿轮间距，再沿相反的方向移回相同的距离，消除齿轮间距并采集图像。测量当前屏幕中心位置与标记点之间的间距。重复上述校准过程3次，计算3次测量结果的算术平均值作为样品台重复性。

（五）定量分析示值误差

使用合金或矿物标准物质进行波谱仪定量分析示值误差的校准，根据标准物质中待测元素的种类，选用电子探针自带标准样品中相同元素的纯金属标准样品或化学组成相近的已知成分的标准样品进行有标样定量分析，重复测量6次，计算6次测量结果的算术平均值，电子探针定量分析示值误差按照公式（6）进行计算：

（6）

式中：Δ*W* —电子探针定量分析示值误差，%；

—标准物质中元素质量分数测量算术平均值，%；

*W*s —标准物质中元素质量分数标准值，%；

（六）定量分析测量重复性

使用合金或矿物标准物质进行定量测试，重复测量6次，定量分析测量重复性按照公式（7）进行计算：

（7）

式中：—第*i*次测量的元素的质量分数，%；

*—*标准物质中元素质量分数测量均值，%；

**—测量次数，**=6。

**三、实验结果**

目前，电子探针的制造厂主要为日本SHIMADZU公司和日本JEOL公司，本课题组对这两家制造厂不同型号的仪器进行现场试验。现场试验所用标准器均相同，具体信息见表1：

表1 现场试验所用标准器信息

|  |  |  |
| --- | --- | --- |
| 序号 | 标准器 | 参数校准值 |
| 1 | 二维标准平面栅格 | 间距长度10034nm，*U*=26nm（*k*=2） |
| 正交角度90.0°，*U*=0.1°（*k*=2） |
| 2 | 首饰金系列成分分析标准物质 | Au：74.99%，*U*=0.04%（*k*=2）  Au：99.994%，*U*=0.037%（*k*=2） |
| 3 | 方铅矿 | S：13.06%，*U*=0.16%（*k*=2） |

（一）实验1

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 制造厂 | | | | 日本SHIMADZU公司 | | | | | | | | | | | | | | | | | | | | | |
| 型号规格 | | | | EPMA-1720 | | | | | | | | | 仪器编号 | | | | | XD20140731 | | | | | | | |
| 实验地点 | | | | 中国科学院上海应用物理研究所上海市嘉定区嘉罗公路2019号 | | | | | | | | | | | | | | | | | | | | | |
| 环境温度 | | | | 22 ℃ | | | | | | | | | 湿度 | | | | | 62 %RH | | | | | | | |
| 1. 长度测量示值误差 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 放大倍数 | | | 方向 | 标准值/nm | | | 测量值  /nm | | | | | | | | | 测量均值/nm | | | 长度测量示值误差/nm | | | 长度测量示值误差的扩展不确定度（*k*=2）/nm | | | |
| 500 | | | X | 10034 | | | 10200 | | | | 10200 | | | | | 10223 | | | 189 | | | 39 | | | |
| 10270 | | | | 10200 | | | | |
| 10200 | | | | 10270 | | | | |
| Y | 10034 | | | 10200 | | | | 10270 | | | | | 10235 | | | 201 | | | 41 | | | |
| 10270 | | | | 10200 | | | | |
| 10270 | | | | 10200 | | | | |
| 1000 | | | X | 10034 | | | 10250 | | | | 10250 | | | | | 10253 | | | 219 | | | 27 | | | |
| 10250 | | | | 10250 | | | | |
| 10270 | | | | 10250 | | | | |
| Y | 10034 | | | 10250 | | | | 10270 | | | | | 10260 | | | 226 | | | 28 | | | |
| 10250 | | | | 10270 | | | | |
| 10250 | | | | 10270 | | | | |
| 5000 | | | X | 10034 | | | 10090 | | | | 10120 | | | | | 10110 | | | 76 | | | 29 | | | |
| 10120 | | | | 10090 | | | | |
| 10120 | | | | 10120 | | | | |
| Y | 10034 | | | 10090 | | | | 10090 | | | | | 10110 | | | 76 | | | 33 | | | |
| 10120 | | | | 10150 | | | | |
| 10120 | | | | 10090 | | | | |
| 2. 正交性误差 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 放大倍数 | | | | 标准值/° | | | 单次测量值/° | | | | | | | | | | | | 测量值/° | | | | 正交性误差/° | | |
| 1000 | | | | 90.0 | | | 90.3 | | | | 90.3 | | | | | 90.3 | | | 90.3 | | | | 0.3 | | |
| 3. 线性失真度 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 放大倍数 | | 方向 | | *X*1/nm | | *X*2/nm | | | | *X*3/nm | | | | *X*4/nm | | | *X*0/nm | | | | /nm | | | | 线性失真度/% |
| 1000 | | X | | 10270 | | 10250 | | | | 10250 | | | | 10250 | | | 10250 | | | | 20 | | | | 0.2 |
| 放大倍数 | | 方向 | | *Y*1/nm | | *Y*2/nm | | | | *Y*3/nm | | | | *Y*4/nm | | | *Y*0/nm | | | | /nm | | | | 线性失真度/% |
| 1000 | | Y | | 10250 | | 10250 | | | | 10270 | | | | 10270 | | | 10270 | | | | 20 | | | | 0.2 |
| 4. 样品台重复性 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 放大倍数 | | | | 样品台重复性单次测量值/nm | | | | | | | | | | | | | | | | 样品台重复性/nm | | | | | |
| 1000 | | | | 800 | | | | | 800 | | | | | | 1000 | | | | | 867 | | | | | |
| 5. 定量分析示值误差与测量重复性 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 元素 | 标准值/% | | | | 单次测量值/% | | | | | | | 测量值/% | | | | 定量分析示值误差/% | | | 测量重复性/% | | | | | 定量分析示值误差的扩展不确定度（*k*=2）/% | |
| S | 13.06 | | | | 13.372 | | | 13.401 | | | | 13.42 | | | | 0.36 | | | 0.07 | | | | | 0.17 | |
| 13.308 | | | 13.500 | | | |
| 13.441 | | | 13.481 | | | |
| Au | 74.99 | | | | 76.888 | | | 77.052 | | | | 76.86 | | | | 1.87 | | | 0.20 | | | | | 0.17 | |
| 76.540 | | | 76.687 | | | |
| 76.942 | | | 77.031 | | | |

（二）实验2

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 制造厂 | | | | 日本JEOL公司 | | | | | | | | | | | | | | | | | | | | | |
| 型号规格 | | | | JXA-8100 | | | | | | | | | 仪器编号 | | | | | XM13200076 | | | | | | | |
| 实验地点 | | | | 自然资源部第二海洋研究所杭州市西湖区保俶北路36号1号楼303室 | | | | | | | | | | | | | | | | | | | | | |
| 环境温度 | | | | 23 ℃ | | | | | | | | | 湿度 | | | | | 58 %RH | | | | | | | |
| 1. 长度测量示值误差 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 放大倍数 | | | 方向 | 标准值/nm | | | 测量值  /nm | | | | | | | | | 测量均值/nm | | | 长度测量示值误差/nm | | | 长度测量示值误差的扩展不确定度（*k*=2）/nm | | | |
| 500 | | | X | 10034 | | | 9931 | | | | 10028 | | | | | 10006 | | | -28 | | | 57 | | | |
| 10067 | | | | 10067 | | | | |
| 10009 | | | | 9931 | | | | |
| Y | 10034 | | | 10240 | | | | 10259 | | | | | 10217 | | | 183 | | | 61 | | | |
| 10259 | | | | 10220 | | | | |
| 10239 | | | | 10083 | | | | |
| 1000 | | | X | 10034 | | | 9954 | | | | 10070 | | | | | 10006 | | | -28 | | | 62 | | | |
| 10090 | | | | 9906 | | | | |
| 10012 | | | | 10002 | | | | |
| Y | 10034 | | | 9933 | | | | 9947 | | | | | 9938 | | | -96 | | | 29 | | | |
| 9961 | | | | 9920 | | | | |
| 9920 | | | | 9947 | | | | |
| 5000 | | | X | 10034 | | | 9969 | | | | 10058 | | | | | 10002 | | | -32 | | | 42 | | | |
| 10038 | | | | 9980 | | | | |
| 9960 | | | | 10009 | | | | |
| Y | 10034 | | | 10044 | | | | 10044 | | | | | 10041 | | | 7 | | | 57 | | | |
| 9926 | | | | 10103 | | | | |
| 10083 | | | | 10044 | | | | |
| 2. 正交性误差 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 放大倍数 | | | | 标准值/° | | | 单次测量值/° | | | | | | | | | | | | 测量值/° | | | | 正交性误差/° | | |
| 1000 | | | | 90.0 | | | 90.4 | | | | 90.4 | | | | | 90.3 | | | 90.4 | | | | 0.4 | | |
| 3. 线性失真度 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 放大倍数 | | 方向 | | *X*1/nm | | *X*2/nm | | | | *X*3/nm | | | | *X*4/nm | | | *X*0/nm | | | | /nm | | | | 线性失真度/% |
| 1000 | | X | | 9392 | | 9295 | | | | 10264 | | | | 10361 | | | 10167 | | | | 872 | | | | 8.6 |
| 放大倍数 | | 方向 | | *Y*1/nm | | *Y*2/nm | | | | *Y*3/nm | | | | *Y*4/nm | | | *Y*0/nm | | | | /nm | | | | 线性失真度/% |
| 1000 | | Y | | 9892 | | 10183 | | | | 9989 | | | | 10183 | | | 9989 | | | | 194 | | | | 1.9 |
| 4. 样品台重复性 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 放大倍数 | | | | 样品台重复性单次测量值/nm | | | | | | | | | | | | | | | | 样品台重复性/nm | | | | | |
| 1000 | | | | 584 | | | | | 825 | | | | | | 930 | | | | | 780 | | | | | |
| 5. 定量分析示值误差与测量重复性 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 元素 | 标准值/% | | | | 单次测量值/% | | | | | | | 测量值/% | | | | 定量分析示值误差/% | | | 测量重复性/% | | | | | 定量分析示值误差的扩展不确定度（*k*=2）/% | |
| S | 13.06 | | | | 13.114 | | | 13.139 | | | | 13.10 | | | | 0.04 | | | 0.06 | | | | | 0.17 | |
| 13.015 | | | 13.136 | | | |
| 13.030 | | | 13.141 | | | |
| Au | 99.994 | | | | 100.941 | | | 99.921 | | | | 99.89 | | | | -0.11 | | | 0.82 | | | | | 0.67 | |
| 99.754 | | | 100.624 | | | |
| 98.654 | | | 99.438 | | | |

（三）实验3

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 制造厂 | | | | 日本SHIMADZU公司 | | | | | | | | | | | | | | | | | | | | | |
| 型号规格 | | | | EPMA-1720H | | | | | | | | | 仪器编号 | | | | | Q12615000049 X4 | | | | | | | |
| 实验地点 | | | | 岛津企业管理（中国）有限公司上海市徐汇区宜州路180号华鑫慧享城B2栋 | | | | | | | | | | | | | | | | | | | | | |
| 环境温度 | | | | 21 ℃ | | | | | | | | | 湿度 | | | | | 45 %RH | | | | | | | |
| 1. 长度测量示值误差 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 放大倍数 | | | 方向 | 标准值/nm | | | 测量值  /nm | | | | | | | | | 测量均值/nm | | | 长度测量示值误差/nm | | | 长度测量示值误差的扩展不确定度（*k*=2）/nm | | | |
| 500 | | | X | 10034 | | | 9970 | | | | 10000 | | | | | 9985 | | | -49 | | | 29 | | | |
| 10000 | | | | 10000 | | | | |
| 9970 | | | | 9970 | | | | |
| Y | 10034 | | | 10000 | | | | 10000 | | | | | 9980 | | | -54 | | | 29 | | | |
| 9970 | | | | 9970 | | | | |
| 9970 | | | | 9970 | | | | |
| 1000 | | | X | 10034 | | | 10000 | | | | 9980 | | | | | 9990 | | | -44 | | | 28 | | | |
| 10000 | | | | 9980 | | | | |
| 9980 | | | | 10000 | | | | |
| Y | 10034 | | | 10000 | | | | 10000 | | | | | 9960 | | | -74 | | | 44 | | | |
| 9880 | | | | 9960 | | | | |
| 9960 | | | | 9960 | | | | |
| 5000 | | | X | 10034 | | | 10000 | | | | 10050 | | | | | 10017 | | | -17 | | | 34 | | | |
| 10000 | | | | 10000 | | | | |
| 10050 | | | | 10000 | | | | |
| Y | 10034 | | | 10000 | | | | 10000 | | | | | 10000 | | | -34 | | | 26 | | | |
| 10000 | | | | 10000 | | | | |
| 10000 | | | | 10000 | | | | |
| 2. 正交性误差 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 放大倍数 | | | | 标准值/° | | | 单次测量值/° | | | | | | | | | | | | 测量值/° | | | | 正交性误差/° | | |
| 1000 | | | | 90.0 | | | 90.0 | | | | 90.1 | | | | | 90.1 | | | 90.1 | | | | 0.1 | | |
| 3. 线性失真度 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 放大倍数 | | 方向 | | *X*1/nm | | *X*2/nm | | | | *X*3/nm | | | | *X*4/nm | | | *X*0/nm | | | | /nm | | | | 线性失真度/% |
| 1000 | | X | | 10000 | | 10000 | | | | 10100 | | | | 10100 | | | 10100 | | | | 100 | | | | 1.0 |
| 放大倍数 | | 方向 | | *Y*1/nm | | *Y*2/nm | | | | *Y*3/nm | | | | *Y*4/nm | | | *Y*0/nm | | | | /nm | | | | 线性失真度/% |
| 1000 | | Y | | 9850 | | 9850 | | | | 9850 | | | | 9850 | | | 10000 | | | | 150 | | | | 1.5 |
| 4. 样品台重复性 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 放大倍数 | | | | 样品台重复性单次测量值/nm | | | | | | | | | | | | | | | | 样品台重复性/nm | | | | | |
| 1000 | | | | 667 | | | | | 625 | | | | | | 812 | | | | | 701 | | | | | |
| 5. 定量分析示值误差与测量重复性 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 元素 | 标准值/% | | | | 单次测量值/% | | | | | | | 测量值/% | | | | 定量分析示值误差/% | | | 测量重复性/% | | | | | 定量分析示值误差的扩展不确定度（*k*=2）/% | |
| S | 13.06 | | | | 13.673 | | | 13.535 | | | | 13.51 | | | | 0.45 | | | 0.11 | | | | | 0.18 | |
| 13.560 | | | 13.372 | | | |
| 13.513 | | | 13.413 | | | |
| Au | 74.99 | | | | 73.710 | | | 73.188 | | | | 73.33 | | | | -1.66 | | | 0.33 | | | | | 0.27 | |
| 73.598 | | | 73.523 | | | |
| 72.919 | | | 73.025 | | | |
| Au | 99.994 | | | | 99.650 | | | 98.142 | | | | 99.54 | | | | -0.46 | | | 1.06 | | | | | 0.87 | |
| 98.356 | | | 100.052 | | | |
| 100.739 | | | 100.279 | | | |

（四）实验4

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 制造厂 | | | | 日本JEOL公司 | | | | | | | | | | | | | | | | | | | | | |
| 型号规格 | | | | JXA-8230 | | | | | | | | | 仪器编号 | | | | | XM1600001920192 | | | | | | | |
| 实验地点 | | | | 中国工程物理研究院激光聚变研究中心  成都市金牛区二环路北一段111号0号教学楼 | | | | | | | | | | | | | | | | | | | | | |
| 环境温度 | | | | 22 ℃ | | | | | | | | | 湿度 | | | | | 58 %RH | | | | | | | |
| 1. 长度测量示值误差 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 放大倍数 | | | 方向 | 标准值/nm | | | 测量值  /nm | | | | | | | | | 测量均值/nm | | | 长度测量示值误差/nm | | | 长度测量示值误差的扩展不确定度（*k*=2）/nm | | | |
| 500 | | | X | 10034 | | | 9956 | | | | 9956 | | | | | 9966 | | | -69 | | | 27 | | | |
| 9975 | | | | 9975 | | | | |
| 9956 | | | | 9975 | | | | |
| Y | 10034 | | | 9956 | | | | 9956 | | | | | 9947 | | | -88 | | | 27 | | | |
| 9937 | | | | 9956 | | | | |
| 9937 | | | | 9937 | | | | |
| 1000 | | | X | 10034 | | | 9731 | | | | 9731 | | | | | 9725 | | | -309 | | | 27 | | | |
| 9713 | | | | 9713 | | | | |
| 9731 | | | | 9731 | | | | |
| Y | 10034 | | | 9749 | | | | 9731 | | | | | 9737 | | | -297 | | | 27 | | | |
| 9731 | | | | 9749 | | | | |
| 9731 | | | | 9731 | | | | |
| 5000 | | | X | 10034 | | | 9863 | | | | 9769 | | | | | 9798 | | | -237 | | | 61 | | | |
| 9712 | | | | 9733 | | | | |
| 9845 | | | | 9863 | | | | |
| Y | 10034 | | | 9756 | | | | 9784 | | | | | 9783 | | | -251 | | | 50 | | | |
| 9705 | | | | 9773 | | | | |
| 9832 | | | | 9846 | | | | |
| 2. 正交性误差 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 放大倍数 | | | | 标准值/° | | | 单次测量值/° | | | | | | | | | | | | 测量值/° | | | | 正交性误差/° | | |
| 1000 | | | | 90.0 | | | 90.4 | | | | 90.3 | | | | | 90.3 | | | 90.3 | | | | 0.3 | | |
| 3. 线性失真度 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 放大倍数 | | 方向 | | *X*1/nm | | *X*2/nm | | | | *X*3/nm | | | | *X*4/nm | | | *X*0/nm | | | | /nm | | | | 线性失真度/% |
| 1000 | | X | | 9731 | | 9713 | | | | 9713 | | | | 9731 | | | 9731 | | | | 18 | | | | 0.2 |
| 放大倍数 | | 方向 | | *Y*1/nm | | *Y*2/nm | | | | *Y*3/nm | | | | *Y*4/nm | | | *Y*0/nm | | | | /nm | | | | 线性失真度/% |
| 1000 | | Y | | 9731 | | 9731 | | | | 9749 | | | | 9731 | | | 9749 | | | | 18 | | | | 0.2 |
| 4. 样品台重复性 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 放大倍数 | | | | 样品台重复性单次测量值/nm | | | | | | | | | | | | | | | | 样品台重复性/nm | | | | | |
| 1000 | | | | 986 | | | | | 814 | | | | | | 1003 | | | | | 934 | | | | | |
| 5. 定量分析示值误差与测量重复性 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 元素 | 标准值/% | | | | 单次测量值/% | | | | | | | 测量值/% | | | | 定量分析示值误差/% | | | 测量重复性/% | | | | | 定量分析示值误差的扩展不确定度（*k*=2）/% | |
| S | 13.06 | | | | 13.544 | | | 13.812 | | | | 13.59 | | | | 0.53 | | | 0.13 | | | | | 0.19 | |
| 13.562 | | | 13.421 | | | |
| 13.649 | | | 13.567 | | | |
| Au | 74.99 | | | | 76.541 | | | 76.870 | | | | 76.33 | | | | 1.34 | | | 0.41 | | | | | 0.34 | |
| 76.216 | | | 75.754 | | | |
| 76.598 | | | 76.012 | | | |

**四、结论**

从总的实验结果来看，规范的校准项目合理、校准方法可行、可操作性强，可以满足电子探针显微分析仪的校准需求。