Evaluation of HOPG mounting possibilities for multiplexing spectrometers

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Abstract

Four different methods for mounting HOPG analyzer crystals on Si holders have been evaluated in the design process of the new multiplexing spectrometer CAMEA. Contrary to neutron optics used in standard spectrometers, the new instrument concept employs a series of analyzer segments behind each other where the neutrons have to pass through the bonding compound of the different analyzer crystals. The different methods, namely screws, shellac, indium soldering and clips, have been evaluated with regards to background, transmission, cooling, activation and handling. The results presented here will give valuable input for future CAMEA-type spectrometers currently planned and designed at various neutron sources.

Keywords: neutrons, neutron optics, neutron scattering, multiplexing, HOPG, neutron spectrometer

1. Introduction

In neutron spectroscopy, e.g. on triple-axis spectrometers (TAS), Bragg reflection from crystals is the most common used method to select a well defined wavelength band from a white neutron beam [1]. For cold instruments, highly oriented pyrolytic graphite (HOPG) is the material of choice for both monochromator and analyzer devices since it has a high reflectivity [2] and can be described as an ideally imperfect non-absorbing crystal. The HOPG crystals are usually mounted on flat metal or silicon holders, which by mechanical rotation can then be used as a focusing device (see e.g. [3]).

In the past decades, two 'standard techniques' for mounting the HOPG have been established, namely glue and screws. Special glues based on a mixture of beeswax and colophonium or 2-component epoxy glue have been used [4], e.g. at the ILL, France, or at the cold TAS FLEXX at HZB, Germany. Often these glues are mixed with a neutron absorber, e.g. GdO_4 powder, to prevent unwanted background arising from scattering of the hydrogen content of the glue or the support material. Another glue material mainly used at PSI, Switzerland, and at some instruments at the MLZ, Germany, is shellac. The second attachment technique is screwing the HOPG crystals on the holder, as e.g. done at the MACS spectrometer [5], which automatically reduces the background. However, it entails certain other risks. First, a hole needs to be drilled into the HOPG crystal. This might result in a local deformation of the lattice and thus a worsening of the mosaic spread around the hole. Second, a certain amount of expensive crystal material is lost due to the drilling. If a spectrometer is at the end position of a neutron guide, the amount of fixing material behind the HOPG crystals of the monochromator, to a certain extent does not effect the downstream performance.

However, due to the excellent transmission properties of HOPG for longer wavelengths [6] there are several realizations where the monochromator of one instrument is placed upstream in the beam of a consecutive instrument, e.g. the RNR12 cold neutron guide at SINQ, PSI, where the instruments NARZISS,

31 ORION, DMC and SANS-II (in downstream order) share one guide or at PEL-
 32 ICAN, ANSTO, Australia [4]. In the latter case, the amount of material other
 33 than HOPG needs to be reduced to a minimum in order to minimize the number
 34 of neutrons scattered out of the beam of the following instruments. In the spe-
 35 cial case of PELICAN, even the single monochromator crystals are consecutively
 36 in front of each other. Here, an alternative fixation method was successfully im-
 37 plemented by using indium as a solder material [4] and realizing large HOPG
 38 crystal by soldering smaller pieces together. Since there are only 3 consecu-
 39 tive monochromator stages and the solder spots are small and thin, the rather
 40 large neutron absorption of the indium can be neglected. Furthermore, since a
 41 monochromator of a spectrometer is normally not changed often, the activation
 42 of the indium in the direct, white beam is likewise not a problem. The method
 43 was also successfully implemented at KOOKABURRA, ANSTO, Australia [7]
 44 by soldering the HOPG crystal of the pre-monochromator to a Si base plate.
 45 Recently, several instruments of a new generation of multiplexing spectrometers,
 46 which use a consecutive series of upwards scattering analyzer arcs to optimize
 47 the efficiency for in plane scattering, have been proposed. This concept has
 48 become know as Continuous Angle Multiple Energy Analysis (CAMEA) [8, 9].
 49 Types of this backend are under construction at the cold TAS RITA-II [10, 11]
 50 at the PSI, Switzerland, [9] and in the design phase for the future ESS source [8]
 51 and the cold TAS PANDA [12–14] at the MLZ, Germany [15]. Furthermore, the
 52 CAMEA-type multiplexing backend MULTIFLEXX [3] has been commissioned
 53 [16] at the recently upgraded cold TAS FLEXX at HZB, Germany, [17, 18] after
 54 successful prototype measurements [19]. CAMEA uses a large amount of HOPG
 55 crystals mounted in series behind each other in the beam and has a rather open
 56 design, i.e, the detectors are sensitive to background arising from neighbored
 57 analyzers. It is thus necessary to evaluate existing and new fixation methods
 58 for this kind of spectrometer.
 59 In the course of the design process of the CAMEA backend at PSI, different
 60 fixation methods have been investigated with regard to background, transmis-
 61 sion, operation in vacuum and durability under cooling. Here, the results for

the evaluation of HOPG fixed with glue, screws, solder and mechanical clips are reported.

2. Requirements

The principal CAMEA instrument would consist of a series of focusing analyzer arcs where each arc is set to a fixed final energy. In reality, these arcs are modeled by angular modules where one module contains several analyzer segments which are placed behind each other to cover the different final energies. A detailed description of the CAMEA concept, the backend constructed at PSI and focusing conditions can be found in [9]. The horizontal opening angle of the angular module (7.5°) and the Bragg conditions of the analyzer segments determine the useful length of the individual HOPG crystals. For the analyzer closest to the sample ($E_f = 3.2 \text{ meV}$, $2\Theta_A = 97.8^\circ$) the HOPG length is much smaller than for the analyzer furthest from the sample ($E_f = 5 \text{ meV}$, $2\Theta_A = 74.2^\circ$). Since frames of the front analyzer segments should not be in the beam in general and especially not in front of the rear crystals, it is not possible to mount the HOPG crystals directly to the frame for CAMEA (HOPG length first and last analyzer segment: 72 mm and 140 mm, respectively). The option of extending the HOPG crystals more than necessary is discarded, since it is expensive, mechanically challenging and increases the background due to neutrons directly scattered into the shielding. Thus, additional supports are needed for the HOPG crystals. For CAMEA, Si was chosen as the holder material since it is stable and large single crystals, which have an excellent transmission for cold neutrons and produce almost no background, are available. The corresponding blades are cut out of standard double side polished (1 0 0) wafers with the (0 1 0) orientation along the long axis. With this orientation the (1 1 1) reflection does not cause any spurious signals in the energy range used for CAMEA. The wafers are nearly perfect single crystals with a mosaicity in the range of a few arc seconds.

Fig. 1 shows the design drawing of an angular segment for the CAMEA spec-

Figure 1: Design of the analyzer segments of one module. The HOPG crystals (blue) are mounted on Si blades (green), which are fixed within aluminum holders (yellow). Figure taken from [9]

Figure 2: Detailed design drawing of the most outer analyzer segment ($E_f = 5$ meV) as seen in Fig. 1. The total HOPG length of 140 mm is achieved by composing two 70 mm long crystals (blue, separation shown by black line). Here the crystals are fixed with the clip solution discussed in section 3.4.

91 trometer currently constructed at PSI. Here, the HOPG (blue) is mounted on
 92 Si blades (green), which are mounted in aluminum frames (yellow). A detailed
 93 design drawing of the most outer analyzer segment (HOPG length of 140 mm,
 94 $E_f = 5$ meV) is shown in Fig. 2. Here the HOPG crystals are fixed with the
 95 clip solution discussed in section 3.4. The total HOPG length of 140 mm is
 96 achieved by the composition of two 70 mm long HOPG crystals due to the fact,
 97 that at the time of the design of CAMEA a maximum HOPG crystal length of
 98 75 mm with the required homogeneity in mosaic spread was available. In fact,
 99 such a composition is necessary for all analyzer segments except for the first one
 100 (HOPG length of 72 mm, $E_f = 3.2$ meV).

101

102 Contrary to the frames, the fixation compound used to mount the HOPG

Figure 3: Analyzer frame of the CAMEA prototype. The frame holds Si wafers. The HOPG is fixed on the Si by aluminum screws. Picture taken from [21].

crystals on the Si blades is in the neutron beam. Thus, the classic and new fixation methods need to be evaluated taking several conditions into account:

- Absorption: The compound should have a low absorption cross section to avoid a reduction of the flux on consecutive analyzer segments
- Scattering: The compound should have a low scattering cross section to reduce additional background and beam attenuation
- Vacuum compatibility: The analyzer will be mounted within a vacuum tank and thus the compound must be suitable accordingly

In the evaluation process, fixation by glue (shellac), screws, solder (indium) and mechanical clips was evaluated. For some of the compounds, the durability under cooling was tested. This is especially interesting for future instruments where the setups might get closer to back-scattering geometry. Here, a cooling of the analyzer crystals can help to suppress the Lorentzian Bragg tails [20].

3. Fixation methods

3.1. Screws

Examples for the fixation of HOPG analyzer crystal with screws are the MACS spectrometer, NIST, and the CAMEA prototype at SINQ, PSI [21, 22]. At the latter, two to three crystals are mounted on long Si blade (see Fig. 3) using aluminum screws. The advantage of this method at room temperature is the easy mounting of the crystal and the replaceability of the crystals. However, a hole or a notch needs to be milled into the crystal. By doing this the

124 crystal mosaicity around the hole/notch might be deteriorated. This has been
 125 observed at the crystals used at the CAMEA prototype. Measurements were
 126 performed on the residual stress diffractometer POLDI, SING [23, 24]. Here,
 127 small areas of the HOPG crystal (sample angle fixed, spot size $1.5 \times 1.5 \text{ mm}^2$)
 128 are investigated using the white beam in combination with the radial detector.
 129 This allows for a fast, detailed scanning of the crystal. A detailed description
 130 of the used setup and exemplary data is presented in [21]. Additional measure-
 131 ments were performed on the multi purpose beamline BOA, SING, [25] using the
 132 energy-selective neutron imaging method [26]. Here, the sample angle was fixed
 133 to 38.8° to diffract a wavelength of $4.2 \text{ \AA}$ - a wavelength in the typical CAMEA
 134 working range. The incident energy was scanned from $4 \text{ \AA}$ to $4.4 \text{ \AA}$ in $0.02 \text{ \AA}$ steps.
 135 A $100 \mu\text{m}$ thick ^6Li -based scintillator screen was used in combination with the
 136 Andor Ikon-M CCD camera [25] ($1024 \times 1024 \text{ pixel}^2$ focused on a $109 \times 109 \text{ mm}^2$
 137 field-of-view) to record neutrons transmitted through the sample. The trans-
 138 mitted intensity as a function of incident energy gives a direct measure of the
 139 mosaicity variations with a spatial resolution of $\approx 100 \mu\text{m}$. A detailed descrip-
 140 tion of the method itself and the setup can be found in [26]. Fig. 4 shows the
 141 map of the fitted Gaussians standard deviation σ_λ of three crystals as measured
 142 [26]. It is clearly visible that the mosaic spread of the crystal around the notches
 143 is slightly deteriorated. One option to avoid this effect would be to make precise
 144 milling masks, which at the same time press on the crystal such that the milling
 145 effect on the edge of the hole/notch is minimized. For a larger spectrometer
 146 with a large analyzer area, this method would drastically increase the amount
 147 of work. Another drawback is the loss of expensive analyzer material due to the
 148 milling.

149 In order to investigate the compatibility for cooling, a frame from the CAMEA
 150 prototype (see Fig. 3) equipped with one Si blade and two HOPG crystals was
 151 mounted on a base plate within a closed cycle CTI and cooled down to 10 K .
 152 To monitor the cooling process thermometers were placed on the bottom of the
 153 base plate, on the frame and on the HOPG in the middle of the frame. The
 154 results are shown in Fig. 5, top. The thermal contact between the holder and

Figure 4: Three crystals from the CAMEA prototype were measured using the energy-selective neutron imaging method. Here, the transmitted neutron intensity at a fixed sample angle is measured as a function of incident energy. The transmitted intensity gives a direct measure of the mosaicity. The fitted Gaussians standard deviation σ_λ is shown. It is clearly visible, that the mosaic spread is slightly deteriorated around the notches. Plot taken from [26], Fig. 5.13 therein.

Figure 5: Top: Test setup temperatures as a function of cooling time. The thermal contact between the different components was found to be good and the the HOPG crystal reached a temperature of 10 K after 24 h. Bottom: Si holders broken during the cooling tests. The holes in the Si clearly weaken the wafer.

the crystal was found to be good and the temperature is reached within 24 h. However, the mounting of the Si blade within a frame could cause additional problems. On one side, a good thermal contact between frame and Si is necessary to ensure the cooling. On the other side, the Si holders can not be clamped tight into the frame, since the Si blade is weakened by the milled holes, which work as a predetermined breaking point, and different thermal expansion coefficients from the frame material can easily break the blade (see Fig. 5, bottom). Estimations on the background arising from additional aluminum in the neutron beam are discussed in section 4. Since aluminum is the only compound necessary for this method, a successful operation in vacuum is not affected.

3.2. Shellac

Shellac is a resinous substance that, dissolved in ethanol, can be used as a adhesive varnish. This method has been used at the PSI, Switzerland, and the FRM II, Germany, to mount HOPG monochromator or analyzer crystals. The fixation procedure is the following: The liquid shellac is applied to the holder and subsequently the HOPG crystal is placed on the holder. The stack is then weighted down with a small weight and the glue is hardened at 90° C in the oven for several hours. The longer the hardening process takes, the better the degassing of the glue. If the hardening process is too short, the adhesive might still be too elastic, resulting in a later shift from the requested position. Furthermore, for use in vacuum, the residual degassing might worsen the vacuum.

176 For test measurements, HOPG crystals from the CAMEA prototype were glued
 177 on Si holders using shellac. It turned out that it is very difficult to apply a
 178 homogeneous, thin film of adhesive such that the HOPG surface is covered with
 179 glue and no excess glue is pressed sideways forming thicker beads. Such beads
 180 would need to be avoided in the CAMEA spectrometer, since they unnecessarily
 181 increase the amount of unwanted material in the neutron beam. Furthermore,
 182 it proved difficult to keep the HOPG in place before starting the hardening
 183 process, since the HOPG is almost free floating on the adhesive film. Due to
 184 the disadvantages in regards of handling and mounting glue was not chosen as
 185 the fixation method for CAMEA and no further investigation on different glues,
 186 e.g. hydrogen-free compounds, was performed.

187 In order to investigate potential effects on the Bragg tails and/or background,
 188 the (0 0 2) Bragg reflection of a HOPG crystal fixed with screws and a HOPG
 189 crystal glued with shellac was measured using the two-axes neutron diffrac-
 190 tometer MORPHEUS at PSI. Sample rocking scans were performed using a
 191 neutron wavelength of $\lambda = 4.67 \text{ \AA}$. A sharp incoming beam ($\lambda_{FWHM} \approx 0.02 \text{ \AA}$)
 192 was obtained using the Si holder of the monochromator as the actual monochro-
 193 matizing beam optics. The results are shown in Fig. 6. The blue data points
 194 (fixation with screw) were scaled by a factor of 0.845 to obtain the same peak
 195 intensity as for the black data points (fixation with shellac). The sum of a
 196 Gaussian and a Lorentzian was fitted to the data. No effect on the tails or on
 197 the background due to the different fixation methods is visible.

198 Additional measurements were performed to estimate the background arising
 199 from shellac. A thin aluminum can (diameter 10 mm) was filled with shellac by
 200 repeatably applying a thin layer of liquid shellac and drying it in the oven. The
 201 incoherent scattering was measured with $\lambda = 4.67 \text{ \AA}$, corrected for the empty
 202 can measurement and compared to the signal from a vanadium rod of the same
 203 dimensions. The incoherent scattering measured is roughly a factor of 2.5 larger
 204 compared to that of vanadium. A comparison of the estimated background with
 205 that of aluminum is discussed in section 4.

206 Vacuum test were performed using one piece of HOPG fixed with shellac. After

Figure 6: Rocking scans performed on the (0 0 2) Bragg peak of HOPG fixed with screws (black) and shellac (blue, scaled with factor 0.845). No difference in background or peak shape is visible.

three days at a pressure of $2.1 \cdot 10^{-7}$ mbar no effect was noticeable. However, no long term test have been performed. Furthermore, since CAMEA employs $\approx 0.45 \text{ m}^2$ of HOPG, a much larger amount of shellac in a larger vacuum vessel might worsen the vacuum quality.

3.3. Indium

The method of connecting HOPG crystals or fixing them to a Si holder using pure indium as solder in neutron beam optics was first used by A. K. Freund *et al.* [4, 7]. As described in [4] indium wets sufficiently cleaned HOPG and Si surfaces well without an additional flux and it can easily be wiped off smooth surfaces.

The initial procedure is to apply indium solder spots manually on the HOPG crystal and the polished Si crystal by heating the crystals to a temperature of 170°C on a hot plate and spread the indium with a small spatula. The two components are then pressed together with a small weight while slowly cooling down. This should be done in a suitable mounting device to ensure a proper alignment of the HOPG crystal on the Si wafer. Since CAMEA employs in total 630 pieces of HOPG crystals, this is a very time consuming procedure. In addition there are up to two HOPG crystals per wafer, which could make alignment more difficult.

A second procedure was tested to allow for a better 'batch production'. The

227 Si wafer was put into a template and small pieces ($2 \times 3 \text{ mm}^2$) of $50 \mu\text{m}$ thick
 228 indium foil were laid on the wafer as solder spots. The HOPG crystals were
 229 put on top and the stack was weighted with a small piece of lead. The stack
 230 was heated up to 200°C for several hours and then slowly cooled down. The
 231 loosening of the connection showed that the indium melted very well. However,
 232 the bonding strength seemed less strong compared to the first procedure where
 233 the surface is manually wetted. In both cases, the connection is very sensitive
 234 to a bending of the Si wafer.

235 It has been shown that oxidation effects the wetting quality and the bonding
 236 strength for fluxless indium soldering [27]. If the soldering process is carried out
 237 under an inert environment, the indium wets the surface more homogeneously
 238 and the bonding strength is increased. Additional tests performed using the
 239 second procedure under inert environment showed good results. Further im-
 240 provement of the bonding strength can be achieved by additionally preparing
 241 the Si wafers with thin sputtered In solder spots before the actual bonding pro-
 242 cess.

243 Indium provides an excellent thermal connection and thus is a good candidate
 244 for cooled analyzer crystals. Cycling the test samples between liquid nitrogen
 245 temperature and room temperature for several times did not show any effect on
 246 the solder connection. Since indium is the only compound used in this method,
 247 operation in vacuum is not affected.

248 Indium has a sizable absorption cross section and produces gamma radiation
 249 after activation. Since the solder spots are thin ($20 - 30 \mu\text{m}$ [4]), the calculated
 250 transmission losses for neutron wavelengths of $4 - 5 \text{ \AA}$ are in the range of 4 %
 251 per solder spot. In order to avoid a series of solder spot and thus a larger at-
 252 tenuation, the spots can be arranged accordingly.

253 Taking into account that each of the HOPG crystals of CAMEA is fixed with 4
 254 solder spots (diameter 6 mm, thickness $30 \mu\text{m}$), a total mass of roughly 15.5 g of
 255 indium is within the neutron beam. Activation calculations were performed us-
 256 ing CINDER'90 [28]. The activation was simulated using a flux spectrum from
 257 inside the neutron guide of the RITA-II beamline (calculated with MCNPX).

258 This spectrum was renormalized to obtain a neutron flux of $1\text{e}4\text{ n/cm}^2/\text{s}$, which
 259 corresponds to a very conservative estimation of Bragg peak intensity illumi-
 260 nating the spectrometer. This intensity is unrealistic for CAMEA, however, it
 261 is a realistic estimate for high flux instruments to be built at the ESS. The ac-
 262 tivation is saturated after a 30-day irradiation with an activity of $8.4\text{ }\mu\text{Ci}$. The
 263 arising background on the detectors can easily be discriminated by threshold
 264 adjustment. After 24 h the activity has already dropped to 0.1%. The ma-
 265 jor gamma emitters in the short term are In116, In116m1 and In116m2, which
 266 have half lives of about 14 s, 54 m, and 2 s, respectively. After a day, In114
 267 and In114m1 are the main gamma emitters, and have half lives of about 72 s
 268 and 49 d, respectively [28]. For CAMEA, the activation would not cause any
 269 problems and/or any additional instrument delay times in case of maintenance
 270 work. However, for spectrometers at the future high flux European Spallation
 271 Source (ESS) this might cause a problem and needs to be taken into account.

272 3.4. Clips

273 The second pure mechanical option investigated is fixation with clips. These
 274 clips are made out of Anticorodal AC110, a stiffer aluminum alloy, and can
 275 easily be cut by wire cutting. A 3D design drawing of such a clip is shown in
 276 Fig. 7. The height of the clip and the stopper are chosen such that the HOPG
 277 crystal and the Si wafer cannot slide out. The width of 2 mm in combination
 278 with the stamp at the end of the clip ensures that the HOPG does not tilt (when
 279 mounted with two clips). The length of the clip can easily be adjusted to the
 280 width of the analyzer crystals. In the case of CAMEA, the analyzer widths vary
 281 between 12 mm and 16 mm. Pressure is applied at three contact points where
 282 the prebending of the clips is chosen such that a compression force of 59 mN
 283 is applied. This has been proven to be sufficient to keep HOPG crystals in
 284 place even during vibrations or after small shocks. The clips are designed such,
 285 that they can be easily mounted from the side by slightly opening them and
 286 carefully sliding the over the crystals. This likewise allows for a nondestructive
 287 dismantling without breaking any connections and/or necessary cleaning. A

Figure 7: Clip solution to fix HOPG crystals on Si wafers.

lateral shift of the HOPG crystals can easily be prevented by adding very thin Si wafers as fences. The thermal contact between HOPG and Si is sufficient for cooling and the different thermal expansions of the different materials can be neglected on such a small scale taking into account the necessary tolerances for mounting the clips. Aluminum is the only compound used in this method, thus operation in vacuum is not affected. Estimations on the expected background due to the additional material in the beam are discussed in the next section.

4. Background estimations for aluminum and shellac

Since each crystal is hold by two aluminum clips and a total number of 1260 clips is needed resulting in an aluminum volume of $\approx 47 \text{ cm}^3$. The same amount of aluminum screws (M2 x 4) including nuts would results in a total volume of $\sim 130 \text{ cm}^3$. In this background estimation only the clip solution is considered. Assuming a $10 \mu\text{m}$ thick shellac layer and a total area of HOPG of 0.45 m^2 a total volume of shellac of 4.5 cm^3 is required. In a first worst case scenario, one can compare the total cross sections (coherent and incoherent) assuming that the aluminum powder lines 'on average' reach the detectors. For the glue the total cross section would be dominated by incoherent scattering. As discussed above, that is a factor of ≈ 2.5 of vanadium resulting in a cross section of $\approx 12.75 \text{ barn}$ ($\sigma_V = 5.1 \text{ barn}$ [29]). Aluminum would be dominated by coherent scattering ($\sigma_{coh} = 1.503 \text{ barn}$ [29]). Thus, the cross section of shellac is a factor of 8.5 higher compared to aluminum. Since a ≈ 10 times larger volume of the aluminum is needed, the worst case estimate of the background for both

311 materials is comparable.
 312 However, in reality it is too pessimistic to assume that the powder lines 'on
 313 average' reach the detectors. CAMEA employs a beryllium filter with a cut-off
 314 energy at 5 meV. Thus, the smallest 2Θ scattering angles are 118° and 163° for
 315 Al(111) and Al(200), respectively. Thus, for single scattering events, the scat-
 316 tering angles would be $> 118^\circ$, which can not reach the detectors in the case
 317 of CAMEA. A minimum of two scattering events is required, which reduces
 318 the probability drastically. In comparison, the incoherent scattering arising
 319 from the shellac reaches the detectors in the amount corresponding to the solid
 320 angle view of the detectors from the analyzers. In the current design this is
 321 $\sim 0.04 \cdot \pi$ (taking into account the additional crosstalk shielding, otherwise it is
 322 $\approx \frac{1}{10} \cdot 4\pi$). Therefore, it can be concluded, that the background expected from
 323 the aluminum clips is much less than the background due to scattering from
 324 shellac.
 325 Taking into account the molecular weight (≈ 586 g/mol) and density (≈ 1.1 g/cm³)
 326 of shellac one can estimate the influence of a Bragg peak irradiating a row of
 327 analyzers. Assuming a Bragg peak flux of 10^4 n/s/cm² and an angular coverage
 328 of 0.25° results in an incoherent count rate of ≈ 50 counts/min arising from
 329 the shellac. This count rate is distributed in 4π and as aforementioned $\approx 10\%$
 330 reach the detectors. The remaining rate of 5 counts/min is distributed on 8 de-
 331 tector segments separated by a cross talk shielding. Thus, per analyzer segment
 332 a background rate of ≈ 0.6 counts/min can be expected which is comparable
 333 with typical background numbers.
 334 For fixation with screws, the number of screws needed is the same as for clips.
 335 The aluminum volume of an M2 screw (including nut and washers) is ≈ 120 mm³
 336 and ≈ 3 times larger than the volume of one clip (≈ 38 mm³). Thus, the back-
 337 ground arising from a screw solution is expected to be larger compared to clips.
 338 However, due to the scattering conditions discussed above, it is still expected
 339 to be much lower than for shellac.

340 **5. Conclusion**

341 Four different methods for mounting HOPG crystals on Si wavers have been
342 evaluated in the course of the CAMEA project. For CAMEA, aluminum clips
343 were chosen as the optimum solution for several reasons: The estimated back-
344 ground due to the additional material is low compared to the incoherent scat-
345 tering of the shellac solution. The dismantling is non-destructive and does
346 not require any additional cleaning, which allows for a quick replacement/re-
347 adjustment contrary to the indium solution. Compared to screws, no holes or
348 notches need to be milled into the HOPG crystals. The mounting of the crystals
349 is not as time consuming compared to the other methods.

350 Another promising method not evaluated here is the direct bonding of HOPG
351 crystals onto Si wavers. This is achieved by hot pressing, which leads to the
352 formation of a bonding SiC in between the crystals. Thus, no additional bond-
353 ing material is in the neutron beam. However, at the time of the evaluation
354 the method was not developed enough to provide the large crystals needed for
355 the CAMEA analyzers. The results on tests of this method will be published
356 elsewhere.

357 The advantages and drawbacks given for the different methods will give valu-
358 able input for the decisions to be made for the upcoming next generation of
359 multiplexing instruments planned and designed at various neutron sources.

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