A Compact Back Face Cooled Slotted Infrared Mirror and Mechanism for the IR 13 Beamline at the SRS, CLRC Daresbury Laboratory

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Abstract

We report on the design and performance of a back face cooled slot relieved infrared mirror and mechanism for the IR 13 beamline at the Daresbury Laboratory SRS. The slot through the mirror allows the 12W/mRad heat load to pass straight through, avoiding severe distortion and damage to the optical face.
A compact fine resolution tilt mechanism and mirror is mounted on a bellows sealed long travel extraction mechanism. The installation position is close to the electron beam and very inaccessible. The extraction mechanism (which allows installation without venting the accelerator) needs to provide maximum stability. The coaxial tilt mechanism must permit extraction past the metal gate valve isolating the accelerator vacuum without disturbing the mirror setting.

Keywords: infrared, flexure, extractable

1. Introduction

Infrared spectroscopy is an extremely powerful probe of materials; it allows rapid chemical analysis from the “fingerprints” of constituent molecules and the elucidation of molecular bonding in new materials from characteristic absorbencies. The technique has wide applications including:

- The identification of drugs and studying their uptake by specific organs of the body.
- The analysis of paint samples for forensic identification e.g. to determine the make, model and year of a car involved in a crime.
- Monitoring quality on production lines.
- Identifying the surface species present on catalysts such as catalytic converters fitted to car exhaust systems, with the aim of improving their efficiency and resistance to poisoning.

Although the conventional “hot body” sources are the routine choice for IR spectroscopy, synchrotron radiation (SR) sources are ideally matched to certain infrared experiments that require higher brightness. These include Infrared Microspectroscopy and Far-Infrared Spectroscopic studies of surface chemistry. The technique of Infrared Microspectroscopy involves focussing the light down to a few microns in order to perform a chemical analysis on samples this size.

Synchrotron radiation provides a hundred fold increase in the signal from such small samples compared to the conventional lab source, and thereby provides much higher sensitivity. By raster-scanning larger samples across the beam in micron steps, a detailed map of the variation in chemical composition can be built up. There is an enormous worldwide demand for such facilities for research in physical sciences, engineering and medicine. As an example of the latter, a multidisciplinary group comprising academic researchers, clinicians and pathologists are using Daresbury infrared beamline 13.3 to study oral cancers [1].

Beamline 13.3 on the SRS is actually optimised for far infrared spectroscopy of surfaces. There are only two facilities in the world which routinely provide sufficiently high quality light for these experiments, namely U4IR at Brookhaven [2] and 13.3 at Daresbury [3]. The difficulty in performing these experiments is well illustrated by work from Daresbury on the manufacture of thermally insulating glass [4]. This glass is coated with tin oxide which, in the UK, is used to reflect heat back into the room and reduce energy loss through the window. The manufacturing process involves spraying float glass with a mixture of tin tetrachloride and water. Little was known of the fundamental chemistry of the process. The chemistry was modelled by depositing silica (model glass) on a highly reflecting metal substrate and reflecting synchrotron infrared light from this. Spectra were obtained by an interferometric process. Exposing the model glass to the tin tetrachloride resulted in the extremely small but highly significant decrease in reflectivity at 379 cm^{-1}. This provides the first evidence for the existence of tin-chlorine chemical bonds on the surface of the glass under certain conditions.

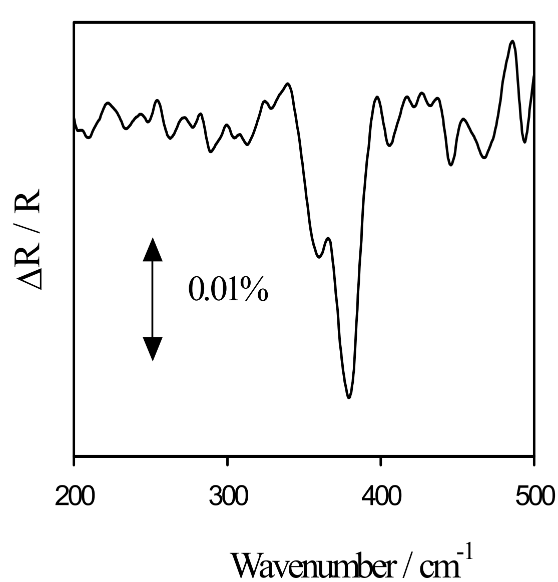

Fig. 1: Change in reflectivity of a model glass sample on exposure to one of the feed gasses used to create low heat loss windows [4].

The weak spectral features observed by this technique are often lost in the noise. In an earlier paper [3] we described a major improvement to the performance of SRS station 13.3 for these measurements obtained by upgrading the interferometer and by improving the stability of some optical components. However, even better performance is required to study complicated surface chemistry in greater detail.

The interferometric procedure used to obtain spectra is particularly sensitive to small movements in the beam with frequencies from a few Hz to kHz. We have identified the existing primary extraction mirror as a source of such instability.

2. Existing Optical System

The primary mirror is an integrally cooled gold coated copper mirror 1.08m from the dipole tangent point (TP) with a water cooled tube acting as a “finger mask” guarding the mirror from the dipole heat load (12 w per horizontal mr of accepted beam). The plane primary mirror set at 45˚ incidence deflects the beam vertically to an ellipsoidal mirror 3.15m away which sets the beam back horizontal and images the source at the UHV window. The UHV window is a 1˚ wedge CVD diamond diffusion bonded to a Conflat mounted inconel top hat and is bakeable to 400˚C (supplied by Special Techniques Group UKAEA, Culham).

The tilt of the mirror optical face is obtained by a linear drive acting upon the large flange and bellows assembly to tilt the vessel and hence the mirror.

The existing optical system mounting to the dipole vessel imposes a number of physical and operational constraints:

- Access to the dipole chamber (from the underside) via a manual (200mm aperture) metal gate valve and narrow 164 x 129mm port.
- Very small space available underneath the dipole vessel to accommodate the vacuum chamber and mechanism.
- The mirror tilt axis should be remotely adjusted to permit alignment with M2.
- The mirror height, reference plane and orientation must be determined and set from precision external survey features.
- The installation of the new mirror system must not require any modification to the dipole vessel or venting of the sector. This means that none of the existing constraints can be significantly reduced or eliminated.

3. New Mirror, Mechanism and Vessel

The existing optical system will be in use until early 2003 and the vessel has the mirror and cooling pipes integrated by welding to the support bellows. Due to these factors it was decided early in the project that a new vessel was essential. The inclusion of a new vessel in the scope of the project enabled a number of important additional improvements to be made:

- In vacuum Conflat mounting of the entire mirror and mechanism. This permits independent assembly and testing of the vacuum and precision motion systems until they must be brought together.

- Larger pumping vessel branch for improved conductance and titanium sublimation pumping speed. This is expected to reduce the conditioning time before the valve isolating the dipole vessel can be opened.

- Improved survey and alignment features to make installation quicker and simpler.

A major design constraint was the 3 sets of bellows necessary to permit the 386 mm travel, which allows the mirror to be withdrawn below the metal gate valve. We were able to modify the bellows sizes (retaining stroke capacity) and significantly stiffen the supporting shaft and bearing system (factor of 6x stiffer). In addition to shaft and bearing housing stiffening the linear bearing size has been increased and changed to ball bushings permitting operation at a very small radial clearance (compared to the existing plain bushings).

The original project objectives were to improve the stability and stiffness of the mirror system as well as removing sources of vibration (such as cooling water). However the lack of a dipole slot absorber (due to the position of the IR extraction port) means that the mirror and mechanism require the protection of a water-cooled absorber. The slotted design of the mirror allows the majority of the on-orbit heat load from the 2GeV stored beam to pass through. This is then caught by the existing absorber on the dipole vessel wall. The mirror body is also cooled using a water cooled copper “shoe” with an indium foil interface to deal with the (much lower) heat load during injection when the beam vertical constraints are much looser.

Mounting a cooled absorber to protect the periphery of the mirror rather than a cooled “finger mask” across the centre of the optical aperture is expected to reduce the “noise” contribution from cooling water flow.

4. Tilt Axis Mechanism

The single tilt axis of the mirror shown in Fig. 2 is designed to give 30μr resolution with a range of ± 3mr. The mechanism comprises a compact custom designed encoded stepper driven screw jack acting upon a lever via a spring loaded contact. The lever is pivoted on a titanium flexure (d) mounted just outside the vacuum system. A small diameter bellows sealed shaft (c) transfers the motion into the vacuum system where a roller (b) is spring loaded into contact with an anvil fixed to the back of the mirror. The operating range permitted by the flexures and bellows requires careful setting up to ensure the specified performance is delivered.

The contact roller at (b) is mounted on an eccentric to facilitate the final setting up of the system. The mirror tilts about an axis assembled by directly bolting to the side of the copper mirror, which is set coincident with the optical face (to a tolerance of ±25μm). A pair of titanium alloy flexures produced by CNC wire spark erosion provides the tilt axis.

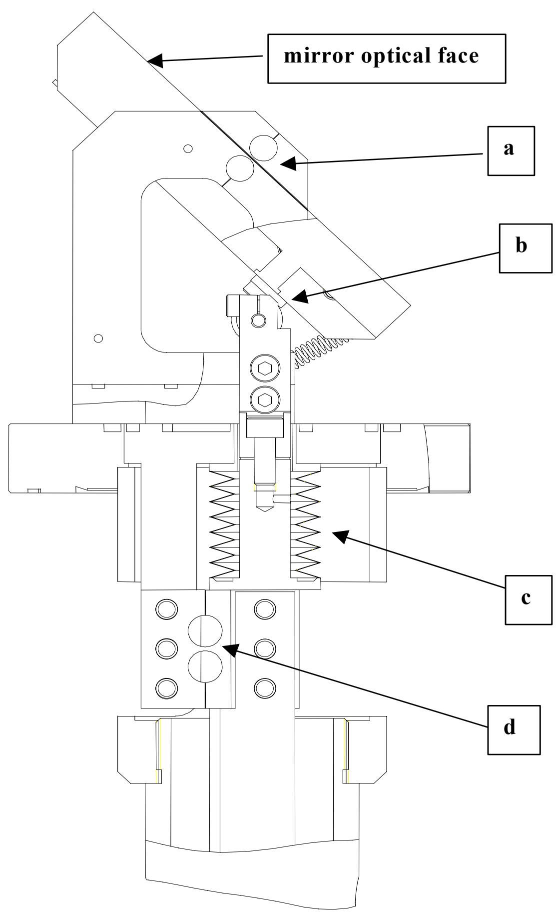

Fig. 2: Single tilt axis of the mirror.

5. Conclusions

Infrared spectroscopy on station 13.3 at Daresbury is an extremely important tool for the study of materials. The engineering developments of the primary extraction optical system are expected to reduce noise permitting the study of weaker spectral features in complex surface chemistry.

6. References

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