

MICRON SCALE SPECTROSCOPIC ANALYSIS OF MATERIALS

A proposal under Mechanism C to the ARC for the establishment of a state-of-the-art Australian Facility for micron scale optical spectroscopic analysis of materials.

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0. SUMMARY OF APPLICATION - ATTACHMENT D**Title of Proposal:**

Micron Scale Spectroscopic Analysis of Materials

Names of Institutions Involved in Co-operative Proposal:

Deakin University
 Monash University
 University of Melbourne

Relationship with other Institutions through Amalgamation or Sponsorship:

None

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Budget Summary:**Amount of Mechanism C Grant Sought -**

| | |
|-------------------------|-----------|
| 1992: | \$510,000 |
| Indicative for 1993/94: | \$50,000 |

Amount of Other Support (please state price level):

| | 1992 | 1993/94 (indic) |
|--------------------------------------------------------------|-----------|-----------------|
| - Institutions (excluding academic staff salaries) | \$490,000 | \$30,000 |
| - ARC Funding (including research grants, key centres, SRCs) | \$95,000 | \$110,000 |
| - Other Commonwealth Competitive Research Schemes (specify) | - | - |
| - Private Sector (specify) | - | - |
| - Other (specify, e.g. State Govt, CSIRO) | | |
| CSIRO Div. of Materials Science and Tech. | \$20,000 | |
| VIEPS | \$10,000 | |
| Telecom | \$5,000 | } applied |
| ICI | \$10,000 | |

1. EXECUTIVE SUMMARY

The goal of this proposal is the establishment of a facility which will enable complete micron scale spectroscopic analysis of any sample which can be imaged in the optical microscope. Such optical analysis is non-destructive, very versatile and requires little or no specimen preparation and can be performed under ambient conditions. The data collected provide crucial chemical and structural information which has been found to be invaluable in the study of biological, chemical and advanced materials systems.

The proposal is driven by researchers with very diverse range of interests in the biological, chemical, geological, physical and material sciences whose common need is for micron scale spectroscopic analysis. Current applications include studies of carbon fibres, diamond thin films, ceramics (zirconia and high T_c superconductors), semiconductors, wood pulp, wool fibres, mineral inclusions, proteins, plant cells, polymers, fluoride glasses, and optical fibres. The range of interests crosses traditional discipline boundaries and augurs well for a truly interdisciplinary collaboration.

Specifically, the proposal involves the purchase of a micro-Raman spectrophotometer to be located in the School of Physics at the University of Melbourne and a Fourier Transform Infra-Red/Raman micro spectrophotometer to be located as part of an instrument centre at Deakin University. Together with existing infrastructure, these two instruments will constitute a state-of-the-art facility unique in Australia in enabling micro-spectroscopic analysis over the whole range of useful wavelengths from the Ultra-Violet (<190 nm) into the Infra-Red (40 μm). The facility will allow researchers from all over Australia to apply the power of micro-Raman, Fourier Transform, Infra-Red, Fourier Transform Raman and UV-Resonant Raman spectroscopies to materials characterization, all on a micron scale.

Developments in instrumentation such as confocal imaging are planned to achieve sub-micron resolution, and advances in computer software and hardware will enable the aforementioned spectroscopies to be used to map molecular and crystalline phases on the surfaces of materials. Coupled with existing compositional microprobes (e.g. the proton microprobe) the possibilities for the development of new, powerful, hybrid imaging technologies appear to be excellent.

Management responsibility will be shared between the three partners, Deakin University, Monash University and the University of Melbourne, with day-to-day running being overseen by the Micro-analytical Research Centre (MARC), in the School of Physics at the University of Melbourne and by a newly established central instrument laboratory at Deakin University. Free exchanges of samples and personnel are expected amongst Monash, Melbourne and Deakin as projects exploit the full potential of the combined micron scale spectroscopic tools which the facility will make available.

2. PARTNERS AND CONTACTS

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3. AIM

To establish a state of the art facility to enable micron scale optical analysis of materials over a wide spectral range from the ultra-violet (UV) to the infra-red (IR), and enable the full power of the following spectroscopic techniques to be applied to a wide class of advanced materials.

1. Micro-Raman spectroscopy
2. Fourier Transform Infra-Red (FTIR) spectroscopy and Fourier Transform Raman spectroscopy (FTIRS).
3. Resonant Raman Spectroscopy (ultra violet (UV) and visible (VIS))
4. Transmission and Reflection spectroscopy from the UV through to the IR on a micron scale.
5. Brillouin scattering (on a limited scale)
6. Raman mapping of surfaces.

4. PHILOSOPHY

The philosophy underpinning such a centre will be to provide to the Australian research community in general and to the partners in particular a facility which will enable complete micron scale optical and spectroscopic analysis of any sample which can be imaged in the optical microscope.

The analysis of advanced materials (ranging from diamonds and diamond thin films through to proteins and biological systems) has already been shown to benefit enormously from such a capacity. Despite this, and the long list of existing projects which need micro-optical analysis, no central facility currently exists in Australia which can provide this service.

Because optical techniques are, in general, non-destructive and require little or no specimen preparation, and because of the rapidity of data collection allowed by modern equipment, the provision of services to a wide range of researchers is practicable, and within the capacity of the proposed acquisitions. Access by outside users (particular those from industry) will be actively encouraged.

5. RESEARCH APPLICATIONS

A brief synopsis of some of the research programs which will make use of the proposed facility are listed below. In each case the proposed facility will provide information not readily available by other complementary techniques.

5.1 MICRO-RAMAN SPECTROSCOPY

5.1.1 The Technique

Raman scattering measurements provide a means of studying the lattice dynamics of solids and liquids, and give insights into the structure, bonding and the nature of disorder in materials. Hence it is not surprising that in recent years micro-Raman spectroscopy has emerged as a powerful diagnostic tool for materials characterization. In this technique a laser beam is focused through a microscope on to the specimen. The scattered light is collected through the same microscope and spectrally analysed. The peaks in the spectrum are characteristic of the microstructure of the specimen. Thus, this technique allows one to view different regions of a specimen and, with micron scale spatial resolution, analyse the composition of the specimen. The technique is non-destructive, very versatile, and requires little or no specimen preparation. Transparent substrates are not required and any region which can be visualized in the optical microscope can be probed with one micron spatial resolution.

Modern photodiode multichannel detectors or CCD imaging systems enable the spectrum to be collected in milliseconds, which opens up applications for semi-real-time analyses (e.g. of creep in strained ceramics). The spectra obtained are fingerprints which can provide crucial new information to aid in the characterization of technologically important materials.

Very recently, Raman microprobing has been successfully used to create a map of the molecular and crystalline phases present on the surface of a specimen. By integrating a computer controlled microscope stage into the system software, rastering permits the sample to be imaged through its Raman signal with one micron resolution. Moreover, the addition of ultra-violet excitation and detection facilities opens up new applications in biology and biochemistry, which have not yet been fully explored.

These advances in instrumentation and the availability of commercial, turn-key, fully integrated systems have transformed Raman spectroscopy into an invaluable tool for materials evaluation, basic research and quality control.

Overseas researchers have come to regard these facilities as standard laboratory tools for materials research and characterization. In

order for Australian scientists to remain competitive in this areas there is an urgent need to upgrade facilities to provide access to state-of-the-art equipment.

It should be stressed that some applications will not necessarily require micron scale spatial resolution. However, even in these cases there is considerable benefit in using a micro rather than a macro spectrophotometer because fluorescence rejection is higher using a micro system. This is because (i) fluorescing impurities are not generally uniformly distributed; and (ii) the higher laser flux can quench the fluorescence. The reduction of fluorescence significantly increases sensitivity and enables new features to be observed.

The only existing micro-Raman spectrometer in Australia, which is available for outside scientific use, is located at the Bureau of Mineral Resources (BMR) in Canberra. Many of the researchers and projects listed below have used this instrument on a contract basis to obtain important new results. Sufficient work has already been done to show the usefulness of micro-Raman spectroscopy and its further exploitation will depend on (a) an extension of the technique to cover a wider spectral range (particularly into the UV - see section 2 below) to facilitate biological and biochemical studies which are not currently feasible on the BMR machine, (b) more ready access for the large number of Victoria-based workers who need to use this technique, and (c) the provision of a scanning facility to enable Raman mapping of surfaces.

5.1.2 The Projects

5.1.2.1 Carbon Fibres

Carbon fibre-based composites are now used in many diverse applications ranging from tennis rackets to aeroplane wings. The mechanical performance of these materials is often limited by the mechanical properties of the fibres themselves. The most desirable combination of properties for fibres is high Young's modulus (i.e. stiffness) coupled with high breaking strength. Unfortunately this combination is difficult to achieve in practice. Polymer PAN-based fibres tend to have low modulus, but high strength, whilst pitch-based fibres tend to have a high modulus, but with low strength. Almost all fibres consist of graphite-like sheets or ribbons as the basic building blocks. Differences in fibre microstructures give rise to the very marked differences in mechanical properties. Hence understanding the connection between microstructure and mechanical properties is an important key to improving fibre properties.

Whilst standard Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) techniques have provided very important information, they do not reveal the entire structural picture. For example, it is not possible to tell from cross-sectional SEM pictures whether large voids which are observed are simply holes of approximate spherical

shape or whether in fact there are long cylindrical holes present in the fibre parallel to the fibre axis. Because of the difficulties in specimen preparation, TEM is in fact quite difficult to apply to the study of fibres and the introduction of defects during the ion-beam milling or microtoming remains, an ever-present possibility. There is clearly a need to develop easy-to-apply, non-destructive characterization tools which will provide quantitative microstructural information which can then be correlated with the mechanical properties.

Raman spectroscopy has proved in the past to be one of the most useful methods for the characterization of all forms of carbon. From the spectrum it is possible to deduce important structural information such as the mean in-plane crystallite size, level of microstructural disorder within the graphite planes, and in some cases the ratio of the amount of graphite-like, 3-fold, sp^2 -type bonding to diamond-like, 4-fold, sp^3 -type bonding. For example, single crystal graphite displays a Raman peak (the "G" peak) at 1580 cm^{-1} . An additional disorder-induced peak (the "D" peak) is found in many other forms of carbon at about 1350 cm^{-1} . It has been established that the ratio of the intensities of these two peaks ($I(D)/I(G)$) is inversely proportional to the mean in-plane crystallite size (L_a) for $25\text{ \AA} < L_a < 2000\text{ \AA}$. Hence a simple measurement of $I(D)/I(G)$ can be used to determine the average crystallite size.

The diameter of carbon fibres is of the order of $5\text{-}15\text{ }\mu\text{m}$ and hence it is necessary to use a micro-Raman spectrometer which can focus the laser beam to a spot of diameter of $1\text{-}2\text{ }\mu\text{m}$. Use of such an instrument makes it possible to collect the spectrum from different sections of the fibre and thus to determine whether the microstructure varies as a function of distance from the fibre core.

The Raman technique is non-destructive, and requires little or no specimen preparation. Correlations between mechanical parameters such as Young's modulus and strength and features of the Raman spectrum have been observed. The second-order spectrum also holds promise for structural characterization. The ultimate goal of such studies is the provision of effective feedback to enable the synthesis of stronger and tougher carbon fibres.

This work is supported by a CSIRO (Division of Materials Science and Technology)/University of Melbourne collaborative grant.

5.1.2.2 Diamond Thin Films

In recent years it has become possible to produce high quality polycrystalline diamond films using low-cost, low-pressure chemical vapour deposition techniques. These films are engineered to take advantage of the many attractive properties of diamond which include extreme hardness, high thermal conductivity, high electrical resistivity, low co-efficient of friction,

high optical transparency and radiation hardness. Applications include tribological coatings for tools and knives, protective coatings for lenses, heat sinks, and ultimately as the basis for very-fast, high-powered, radiation-hard, semiconductor devices. Despite the extraordinary advances in diamond thin-film technology little is understood about the mechanism for diamond thin-film growth which occurs under conditions in which graphite, and not diamond, is the thermodynamically stable form of carbon.

Distinguishing between crystalline diamond and graphite is not difficult. However, diamond films can exist as a multiple phase material with evidence for the presence of sp^3 (diamond like), sp^2 (graphite-like), and amorphous material. Raman spectroscopy is perhaps the only technique which is able to distinguish unambiguously, and at least semi-quantitatively between these different phases of carbon. In particular Raman spectroscopy has proved to be invaluable as a truth test for the presence of polycrystalline diamond in a mixture of amorphous carbon and/or micropolycrystalline graphite. As most diamond films display grain sizes of the order of 1-10 microns, once again micro-Raman techniques are essential.

From the above it is clear that Raman spectroscopy is an invaluable tool in optimising the deposition conditions for the production of high quality polycrystalline films. However, in addition micro-Raman has recently been employed by S. Praver in a number of important fundamental studies relating to diamond film growth. In one such study, important correlations between film quality (i.e. lack of defects) and film purity (i.e. absence of non-diamond phases) were reported. These studies suggested that defects occur as a result of particle overgrowth and that fundamental limitations to particle quality lie not in the intrinsic growth mechanism, but in the way particles interlock to form a continuous film.

Further to these studies micro-Raman measurements were used to compare the quality of the different faces of the same 10 micron sized particle. It was found that the (111) faces contained more amorphous carbon than the (100) faces suggesting that the growth mechanism may be very different for the different growth directions and that the key to high quality diamond growth may lie in forcing (100) morphologies rather than (111) type growth. Thus, micro-Raman spectroscopy is proving to be an essential element in the emerging understanding of the mechanism for metastable diamond thin-film growth.

This work is supported by an ARC postdoctoral fellowship, an industrial grant with CRA-Advanced Technical Development and an ARC postgraduate industry research award.

5.1.2.3 Ceramics

Raman spectroscopy provides a most useful probe for studying the microstructure of certain ceramic materials. Unlike x-ray diffraction which

has been a more widely used materials characterisation technique and for which phase identification can often be hindered by overlapping diffraction peaks, features in the Raman spectrum from structurally related phases will often be well resolved. In particular, zirconia-based ceramics have been extensively studied using the existing macro-Raman spectrometer in the Department of Physics at Monash University and the high- T_c superconducting oxide ceramics have been examined by Monash researchers through access to the micro-Raman spectrometer at the Bureau of Mineral Resources, Canberra.

There are various problems of current interest within the area of zirconia-based ceramics:

- (a) The deformation under load (including tension, compression and bending) of PSZ in the vicinity of room temperature.
- (b) The influence of moisture on the structural properties of zirconia-based ceramics.
- (c) The influence of grain size on the microstructural changes produced by deformation.
- (d) The microstructure ahead of a crack induced in PSZ and wear hardness indentations in Y-TZP.
- (e) The possibility of the wider application of Raman spectroscopy to the quality control of zirconia-based ceramics.

While (a), (b) and (c) are already being extensively researched at Monash in a programme involving three Academic Staff, one Australian Research Council Post-Doctoral Research Fellow, three Graduate Students and some existing collaborative research between Monash and CSIRO, Division of Materials Science and Technology, microstructural measurement using the existing Monash based macro-Raman spectrometer is slow and the determination of the kinetics of microstructural changes very limited. (d) could only be addressed on a micro-Raman facility and before attempting to 'educate' Australian industry to consider (e), a more reliable spectrometer than that currently available to the Monash group, would be required.

The work on high- T_c oxide ceramics which can only be done using the micro- (and not macro-) technique, is concerned with the microstructure of grain boundaries and the assessment of oxygen content within discrete grains of the sample. The work is closely related to a more extensive project concerned with the flux pinning properties of these materials.

5.1.2.4 Semiconductors

Micro-Raman spectroscopy has been very effectively used to monitor many important physical parameters of ion implanted and laser

annealed semiconductors. Properties which can be effectively probed include residual strain, amorphous to crystalline fractions, and level of crystalline perfection, as well as more sophisticated examinations of the fine details of the band structure using resonant Raman techniques. In one impressive demonstration of the power of the technique the degree of recrystallization and level of residual strain was mapped as a function of position in a 50 μm laser-irradiated spot on a previously amorphized Si wafer. In another application, workers at IBM (Zurich) produced a spatially resolved map of the actual operating temperature of a laser diode was determined by micro-Raman spectroscopy via an examination of the relative intensities of the Stokes and anti-Stokes Raman lines. Despite these overseas successes, Australian semiconductor researchers have not been able to fully exploit the power of Raman spectroscopy, partly due to lack of ready access to state-of-the-art facilities.

However, two semiconductor projects currently underway which use the Raman are:

- (a) Studies of disorder in semiconductor crystals silicon and diamond. This project involves the use of the Raman line shape to estimate defect levels within ion-beam-irradiated solids. Although silicon is being used as a starting material, the goal of this research is to elucidate the very peculiar behaviour of diamond as a function of ion dose for dose levels less than those which cause graphitization. The difficulty in the past of applying Raman spectroscopy to the ion-implanted layers results from the transparency of the underlying, unmodified diamond. The project underway to attempt to overcome this difficulty involves exploration of both surface enhanced Raman technique and polarization measurements. This project is being jointly undertaken by Monash University (Dr F. Ninio) and the University of Melbourne (Dr S. Prawer).
- (b) Studies of implanted and annealed, bulk $\text{Hg}_x\text{Cd}_{1-x}\text{Te}$ (MCT). This project focuses on ion-beam-induced disorder and change of stoichiometry as a result of the annealing process. This project is to be undertaken in a collaboration between the University of Melbourne (Dr S. Prawer) and the Technion, Israel (Professor R. Kalish).

5.1.2.5 Wood Pulp

It has already been demonstrated that the polarised Raman spectra of cellulose fibres obtained with a microprobe facility is dependent on the orientation of the plane of polarisation with respect to the fibril axis. The technique has also been used to observe changes in the crystallinity of eucalypt pulp fibres caused by press drying.

Advances in the breeding of eucalypts for improved pulp production are dependent on the development of techniques for improving fibre properties which in turn depends on the development of more sophisticated characterization tools. Within the Australian Pulp and Paper Institute in the Department of Chemical Engineering, Monash University, research is in progress, through which it is hoped to contribute significantly to this field. One trial experiment has been conducted using the existing micro-Raman spectrometer at the BMR, partly as a familiarization exercise for research staff involved. The results were sufficiently encouraging to indicate that the ready availability of a micro-Raman spectrometer to the staff of the Institute, will be of considerable benefit to the research being planned for the next few years.

5.1.2.6 Wool Fibres

A knowledge of the physical and chemical heterogeneity of both natural and treated wool fibres is necessary if a full understanding of the properties of wool and improvements in various chemical treatments are to be achieved. There is inadequate knowledge of the chemical composition of the various surface features of the wool fibre and the distribution of various chemical treatments (e.g. stain-blocking treatments) over the fibre surface are difficult to determine by conventional methods. Micro-Raman spectroscopy offers the opportunity to record vibrational spectra of wool keratin protein and chemical treatments with a spatial resolution <1 micron. Rastering of the focused laser beam over the sample combined with synchronised CCD detection offers the potential to record a "chemical map" of the fibre surface. The application of such measurements should result in detailed chemical information being obtained on the surface composition of natural and treated wool fibres which will permit future improvements in fibre treatments.

The Australian Wool Corporation is supporting studies in the general area of micro-spectral analysis through a Postgraduate Scholarship with Dr K.P. Ghigginio, Department of Chemistry, University of Melbourne.

In addition Deakin University is a partner with CSIRO in a bid for a CRC in Wool Science and it is anticipated that these studies will be expanded in Geelong. Given the expansion of the CSIRO activity in this area, enhanced research effort in wool fibres is anticipated notwithstanding the success (or otherwise) of the CRC proposal.

5.1.2.7 Polymers

Heterogeneity on a micron scale in polymeric coatings and films may be present on a micron scale on account of aggregation of additives, phase separation in incompatible polymer blends and defects in film formation. Such heterogeneity and defects can ultimately determine the properties and endurance of polymeric materials. As part of an on-going

program investigating polymer miscibility and dispersion behaviour of additives, micro-Raman techniques would provide a powerful, additional tool to resolve spectrally and spatially the chemical constitution of polymer substrates.

5.1.2.8 Fluid Inclusion Analysis (Geology)

Both micro-Raman and Fourier transform infra-red (IR) microspectroscopy (see below) have the capability to allow fast, reliable, non-destructive, in-situ analysis of individual fluid or solid inclusions in minerals. The techniques are complementary in that Raman provides the best spatial resolution, whilst fluorescence rejection is better accomplished using an IR technique. Both techniques have become important tools for the geologist to study the relative abundances of species (e.g. SO_4^{2-} , CO_2 , CH_4) and for the identification of solid inclusions, daughter minerals, and organic components in oil-filled inclusions.

The Victorian Institute for Earth and Planetary Sciences (VIEPS) has a number of important projects in train which use the existing BMR micro-Raman facility. One of these is the study of quartz veins associated with gold mineralization. However, the researchers involved believe that an expansion of the use of the technique would result from an instrument being located in Melbourne. Also no FT-Infrared microspectrometer is currently available to researchers in Victoria and as indicated above, FTIR and Raman are complementary techniques for this study of inclusions. Accordingly, the three Departments of Geology at the University of Melbourne (Dr Malcolm Wallace, Professor R. Plimer and Dr Reid Keays), Latrobe University (Dr Teunis Kwak) and Monash University (Dr Mark Bloom) via VIEPS have indicated their financial support for the facility. Expected usage will be about three weeks/year. In order to study fluid inclusions effectively it is necessary to freeze the fluid. Hence, a freezing stage will be added to the spectrometers for the geological work.

5.1.2.9 Other

Other applications include bone (Monash), MOCVD semiconductors (Telecom), fluoride glasses, and optical fibres (Telecom).

5.2 UV-RESONANT RAMAN (UVRR) SPECTROSCOPY

5.2.1 The Technique

The advent of the laser revolutionised Raman spectroscopy and, more recently, the use of different wavelengths, Fourier Transform methods, and resonance enhancement have extended its applicability. The use of improved signal detection and signal processing methods have further enhanced its utility. Resonance Raman spectroscopy enables an increase in the sensitivity of the Raman technique by tuning the excitation source close

to an absorption of the species being probed. Enhancement in scattered light intensity is obtained for those vibrational modes which mimic the molecular distortion in the resonant excited state. The majority of these studies have been made using visible wavelengths and this has limited the range of chromophores examined. Laser sources producing reasonable power in the U.V. enable the extension of the resonance technique to a wide range of protein residues and small molecular species. The technique promises to be extremely useful in the study of proteins and polypeptides and these applications have been reviewed by a number of authors. The technique of U.V. Resonance Raman (UVR) spectroscopy is not currently available in Australia.

The technique of micro-Raman has not, to date, been used in UVR studies. The potential of such studies in the examination of intracellular processes is an extremely exciting area for development. It would, in addition, enable studies to be made in the developing forefront of world science in cellular biotechnology. Applications in biomedical research are also anticipated. A study of plant membranes is proposed as the initial area of development as described below.

5.2.2 The Projects

5.2.2.1 Structural Studies in Protein Biotechnology

One of the recent advances in Raman spectroscopy has been the use of laser sources in the ultraviolet in studies of biological molecules. This has enabled the resonance enhancement of features associated with a greater variety of chromophores than can be utilized with visible laser sources. Examples include the purine and pyrimidine bases of nucleic acids, aromatic side chains of proteins and the peptide bond itself. The derivation of structural information through localised probing of the protein or peptide structure provides a valuable and unique source of information to integrate with other techniques, in the establishment of molecular structures.

A prime example is the amino II band which becomes very strong in the UVR spectra and depends strongly on polypeptide conformation. This provides a method for probing protein secondary structures. Thus two measurements with exciting wavelengths 200nm and 192nm can give the fractions of α -helix and γ -sheet. The enhanced sensitivity (1000 fold) and residue specificity of the method overshadow the widely used UV circular dichroism. As a consequence of the ability of aromatic side chains to produce strong resonance enhancement in the UV, the environment near phenylalanine, tyrosine, tryptophan and histidine can be probed by UVR. It appears likely that local conformational features, hydrophobic interactions and hydrophobic bonding in the vicinity of the residues can be examined with some selectivity. Proline can also be examined and the technique holds promise for monitoring the cis/trans isomerisation of proline which may be important in protein folding kinetics.

The folding of a chemically synthesised protein is complex. Unlike cloned material the protein is prepared in a completely unfolded state and then is "folded" by a variety of empirically based treatments - to date there is no useful spectroscopic technique that can monitor the folding process in micromolar concentration of the protein. UVRR investigation of the cis/trans ratios of the proline residues holds great promise to allow us to follow the folding process directly.

The secondary structures of the neuropeptides (3-40 residues) play important roles in eliciting a biological response. Though they are thought to possess similar structural features (beta sheets, helices and loops) to their larger protein counterparts, the evidence for this is largely indirect and sparse. Recently NMR evidence has emerged which suggests that many small bioactive peptides have a predominant solution conformation which commonly is maintained by one or more intra-H-bond arrangements (C=O...H-N), typically where a b- or g- turn is found.

5.2.2.2 Ion-Ion-Solvent Interactions

Raman Spectroscopy has proved to be a particularly useful technique in the elucidation of both solvation and ion association interactions in electrolyte solutions. The extension of the spectroscopic measurements into the dilute solution regime remains a problem of central importance. Equilibrium and transport measurements over the last 50-60 years have produced data of great reliability and precision. The interpretation of this data is however model dependent because the nature of the solution equilibria is not certain. The spectroscopic methods have the capacity to clarify the problem if the appropriate measurements can be completed.

A further series of studies is proposed to make use of the UV capabilities of the instrument. The nitrate ion has a weak laPorte forbidden transition in the UV region at 260nm. This has been assigned to an Π^*-n transition which involves electron movement towards the oxygen atoms. This spectral feature is strongly influenced by the nature of the counter ion in fused solid studies while in aqueous solution the studies are less extensive but a moderating influence by the solvent is apparent. The ion also has a $\Pi^*-\Pi$ transition which is not well characterised but which produces an intense absorption near 100nm. It is proposed that much of the variation in the $\Pi-n$ transition occurs through perturbation of the Π^* and so the effects should also be apparent in the $\Pi^*-\Pi$ transition.

5.2.2.3 Structural and Dynamic Studies in Plant Biotechnology

Cell walls play a critical structural role for overall plant function and, as one of the major repositories of plant biomass, they are also important as an energy sink. Cell-wall integrity is therefore important for overall plant yield and also for plant digestibility and nutritional value to

both humans and animals. Cell-wall structure determines the fibre characteristics which are ultimately the basis of the massive forestry-derived pulp, paper and timber processing which constitutes Australia's second largest manufacturing industry. Methods to accelerate plant improvement through genetic engineering and interspecific cell hybridization are seriously complicated by the presence of the cell wall and by difficulties in its regeneration from protoplasts if removed.

The walls of plant cells are complex structures composed of a number of classes of molecules including cellulose, hemicelluloses, pectins, and xyloglucans, as well as cell-wall proteins and lignins. The relative proportions of these different components can vary considerably with plant species, tissue-type, and stage of cell growth and differentiation. The chemical analysis of various extracts and degradation products has figured prominently in studies to characterize the cell wall. However, the present state of knowledge remains very poor in comparison with other areas of plant biochemistry. This is due to inherent limitations in the techniques employed. Staining methods are often not highly discriminatory and are potential causes of artifacts arising from the binding reactions themselves; electron microscopic studies of isolated components do not shed much light on the integrated structure. The generally powerful methods of NMR and X-ray crystallography are not yet capable of yielding detailed information on such a complex heterogeneous structure.

Understanding in this area will undoubtedly be advanced by the development of methods capable of providing detailed chemical structural information on cell wall components with high sensitivity and spatial resolution in a continuous and non-invasive way. The new technique of UV Resonance Raman (UVRR) spectroscopy appears to be a very powerful new method which has many of the sophisticated characteristics necessary to obtain the essential information needed to advance understanding of cell-wall structure. Indeed, the instrument is ideally suited to these requirements.

In these studies the UV absorption of selected cell-wall components (for example, the aromatic groups and peptide links in proteins, acetylated residues of xyloglucans, and the aromatic rings of lignins) will be used to provide the resonance enhancement of the signal. Using the microscope sample method, spatial resolution to better than 2 μm is readily achievable and will allow profiling of molecular structural information across the cell wall to be accomplished. The use of multichannel detection will allow the time variation of the signal to be followed. Although it is not possible to define the time resolution which will be achieved (because no comparable studies have been attempted), we are confident that because the processes are relatively slow (seconds to minutes or greater half life) that adequate time resolution will be achieved. We propose studies including: the characterization of cell-wall components across different cells in intact tissues; wall composition changes during expansionary growth of the cell;

monitoring removal of specific cell-wall protoplasts; and determination of the compositional changes induced by deficiencies of boron, copper, calcium and manganese which affect cell-wall integrity. This powerful new technique has not been applied previously to the study of cell-walls, but it is a timely development which promises enormous potential for this important area of plant science.

5.2.2.4 Structural Studies in Polymer Systems

The conformational properties of poly (electrolytes) in aqueous solution and vinyl aromatic polymers in organic solvents is a subject of considerable fundamental and practical interest. Photophysical studies of poly (electrolytes) containing aromatic groups have indicated the formation of pseudo-micellar structures which collapse as the pH and ionic strength are altered. Such polymers mimic protein conformations and have applications as unique environments for carrying out catalytic chemistry. However, photophysical measurements cannot provide the structural detail that UV Resonance Raman spectroscopy can offer. In particular, Raman spectroscopy has the potential to reflect local conformational features which could explain the interactions which favour stable polymer structures. In vinyl aromatic polymers the close proximity of aromatic groups along the polymer chain (3-4Å apart) allows the possibility of interaction leading to dimer formation, and energy migration and trapping upon UV excitation. To date no detailed information on the nature of the ground state interactions in such polymers is available, data that UV Raman could provide.

5.3 FOURIER TRANSFORM RAMAN SPECTROSCOPY

5.3.1 The Technique

This is a novel technique first reported in 1986. It has a pronounced advantage over conventional Raman spectroscopy in the area of fluorescence elimination. Because excitation is moved to the near IR where the chromophores usually associated with fluorescent emission do not absorb, the problem of fluorescence masking the Raman spectra is minimised. Because the technique has the advantages associated with Fourier transform methods the spectra are more easily recorded and manipulated than conventional spectra.

5.3.2 The Projects

There is currently no FT Raman installation in Australia though QUT has an instrument on loan. Because of the newness of the technique there is still much fundamental work necessary to assess the applicability of the technique in a range of situations.

5.3.2.1 Solution Studies

Initial work at QUT has demonstrated the utility of the technique in the examination of Raman spectra of solutions. These projects would be expanded with the intention of elucidating the nature of the ion-ion-solvent interactions. Analysis of line shapes and deconvolution of complex bands would be facilitated by the on-line capability of computer programs.

5.3.2.2 Studies of Metal-Ligand Bonding

For many metal complexes involving large organic ligands fluorescence continues to be a major obstacle in the determination of Raman spectra. These spectra frequently provide the most direct evidence of coordination geometry. These studies are of importance in both fundamental studies of complexes and in studies relating catalytic activity to catalyst structure.

5.3.2.3 Forensic Studies

FTIR has proven to be a most useful technique in forensic science. The Raman technique has been less useful because of low sensitivity. The FT Raman technique has promise in overcoming the sensitivity problem. Since it can be used with samples in all states of aggregation, its use in forensic analysis would be considerable. This aspect has not yet been developed and proven.

5.3.2.4 Studies in Aquatic Sciences

An extensive program in aquatic science and marine toxicology is currently being pursued at Deakin University. While GCMS is an invaluable tool in the examination of samples for toxicology testing, the methods of testing for organic residues on a routine basis are not well developed. The presence of chromophores with strong scattering cross sections will enable the use of FT Raman spectroscopy as a sensitive analytical tool for a range of toxic residues.

The scope of the technique in studies of aquatic systems extends to a variety of studies. Because of the existing wavelength used, the minimisation of fluorescent interference and the enhanced sensitivity of the Fourier transform technique, analytical information on a wide range of solution constituents may be obtained without extensive pre-processing of the solutions.

5.3.2.5 Studies in Polymer Systems

There has been extensive development of FT Raman in overseas laboratories for the study of polymer systems. The FT Raman system will be an invaluable complement to both the UVR and FTIR (see below) methods in the polymer and wool studies proposed.

5.4 FOURIER TRANSFORM INFRA-RED (FTIR) MICRO-SPECTROSCOPY

5.4.1 The Technique

Fourier transform infrared spectroscopy is a well established technique both for research and routine investigations. Raman and infrared methods are complementary aspects of vibrational spectroscopy and research applications usually require the use of both techniques. The FTIR spectrometer will be a high-resolution instrument with an extended midinfrared capability. The range overlaps that available through the FT Raman equipment which can be operated as an FTIR instrument. This gives an operating range from 10000cm^{-1} to 400cm^{-1} . The spectrometer would be fitted with a microscope to give complementarity with the visible/UV Raman spectrometer.

5.4.2 The Projects

(a) The projects listed under 5.1.2 (particularly 5.1.2.8) will be appropriately extended using the FTIR technique. Because of the complementarity of the scattering and absorption methods this will ensure that a much more comprehensive spectroscopic profile can be obtained. The microscope capability of this instrument will be an essential component of this complementarity. It is very important to stress the value of this complementarity particularly for fluid inclusion work (section 5.1.2.8). Since active Raman modes are often IR inactive and vice-versa, an analysis of inclusions is considered to be incomplete until both Raman and IR measurements have been taken. The spatial resolution in the midinfrared is less than in the visible and UV regions because of the diffraction limit associated with the larger wavelength. However spatial resolution of 5 - 10 μm is often achieved and this will enable parallel observations to be made.

(b) The projects listed under 5.3.2 will also require the complementary use of the FTIR and microFTIR technique.

5.5 DEVELOPMENTS IN INSTRUMENTATION

5.5.1 Spectral Analysis Using Confocal Imaging

Confocal microscopy is rapidly becoming an invaluable tool for imaging samples with high lateral and transverse resolution. It also allows the optical sectioning of translucent objects, thus eliminating many sample preparation techniques. It is the absence of the defocussed image elements from the optically sectioned planes that results in the enhanced image clarity compared to conventional microscopes. The confocal apertures

(excitation/detection pinholes) form a restricted volume element on the sample focal plane which can be rastered either by sample movement or optical scanning techniques to produce an image or map of the surface.

The development of fluorescence, reflectance and Raman confocal microspectrometers would allow high-resolution spectral data to be obtained on the micron and sub-micron spatial scale. By scanning of the laser excitation source, a "spectral map" of an optically sectioned plane within the sample can be obtained. These spectral maps could characterize the distribution of chemical species within, for example, a biological cell, textile fibre or polymer surface coating.

The combination of laser excitation sources, spectrometers and confocal micro-imaging systems would provide powerful new analytical tools. Such novel systems are being developed within the Chemistry Department at the University of Melbourne (Dr K.P. Ghiggino) and their further development and application would occur on the proposed micro-Raman spectrometer.

5.5.2 Non-Destructive Raman Mapping of Surfaces

The Raman microprobe technique offers the opportunity in principle to create a map of the molecular and crystalline phases present on the surface of a sample, by rastering the sample under the laser beam. Recent developments in data acquisition, computer control and detectors have made production of such maps a reality, although much work needs to be done before Raman mapping can be considered to be a standard analytical tool.

One of the limitations is the sheer quantity of data which needs to be stored if a complete spectrum is to be taken at each point. Usually this necessitates imposing windows on the spectrum. However, Total Quantitative Scanning Analysis (TQSA) pioneered by the Micro-Analytical Research Centre at The University of Melbourne for the analysis of data from the proton microprobe, has shown that it is possible to collect and store all the data for later off-line processing and analysis. Line scans or maps of all species can be called up, or alternatively spectra of any shaped region can be extracted. This is in general not possible where data are collected in windows. Thus a proposed development will be to apply TQSA to Raman spectra for scanning purposes. Immediate applications will focus on the biological systems and Raman mapping of cells using UV resonant Raman techniques. The structural information gained will be combined with the compositional information available from the proton microprobe to provide an extremely powerful hybrid mapping capability.

6. COLLABORATIVE ARRANGEMENT PROPOSED

This proposal brings together groups with a very wide range of interests whose common ground lies in their need for access to state-of-the-art, micro-optical analysis facilities. Table I (page 30) outlines some of the interests and existing expertise of the partners and other interested parties.

As mentioned above the aim is to provide complete optical analysis of any sample which can be imaged in an optical microscope. In practice, one machine cannot perform this task over the whole of the spectral range. Hence two machines with complementary capabilities will be installed, one in the School of Physics at the University of Melbourne, and the second at Deakin University.

Machine A will be a state-of-the-art micro-Raman spectrometer capable of 1 micron spatial resolution and covering the range from 190nm - 1 micron. This machine will provide users with the best available spatial resolution, fast counting times and good resolution. This machine will be located at the University of Melbourne (as part of MARC - see below) and will service the existing needs of the materials science community in the first instance, and will gradually be developed (see below) to enable users from the biological and bio-chemical sciences to benefit from its micron scale capabilities.

Machine B will be a FTIR/FT-Raman equipped with an optical microscope. The range covered will be 1-40 micron, with excellent spectral resolution and very fast counting times. This machine will be located at Deakin and will provide very rapid turn-around on biological, chemical and bio-chemical type samples.

It is important to stress that because of the complementarity of the information obtained from scattering (Raman) and absorption (IR) methods the ready availability of both machines will ensure that a much more comprehensive structural picture can emerge (often Raman active bands are not IR active and visa-versa). Thus, for example, studies of inclusions in minerals would not be considered to be complete until both Raman and IR measurements have been performed.

Thus, the purchase of two machines will strengthen collaborative links because most projects will benefit from access to both Raman and IR measurements.

6.1 IMPLEMENTATION

The desire of the partners to provide complete UV-IR coverage on the micron scale will be implemented in two stages which will enable this goal to be achieved by maximizing the use of existing facilities and expertise. It should be noted that the implementation will involve the physical transfer

of an Ar laser from Deakin to the University of Melbourne, in order to minimize capital outlay, and to facilitate a strong co-operative centre. Of course as mentioned above, the complementarity of the information provided by Raman and IR will also strengthen the collaborative links.

Collaborative links between researchers at the University of Melbourne and Monash University are already strong in the materials science area with a number of semiconductor, and diamond based projects currently underway. The expertise developed at Monash in both theory and application of Raman spectroscopy is a crucial ingredient in the success of the collaborative effort.

Stage 1 (1992): Installation of machines A (Melbourne) and B (Deakin). At this stage an Ar ion laser will be transferred from Deakin to the Melbourne machine which will enable micro-Raman spectroscopy to be carried out immediately in the visible region of the spectrum. Although the Ar laser will have some limited UV capability, the very powerful technique of UV-Resonant Raman spectroscopy on a micron scale will not be implemented on machine A in Stage 1 as it requires the provision of a suite of UV lasers which are located at Deakin, which require specialist technical assistance for consistent reliable operation. However, micron-scale UV absorption measurements would be available immediately.

Projects which will proceed immediately include carbon fibres, diamond films, ceramics, semiconductors, wood pulp, wool fibres, polymers, and fluid inclusion work, using both micro-Raman and micro-IR spectroscopy. At Deakin work on solution studies, studies of Metal-Ligand bonding, forensic studies, and studies in aquatic science will proceed, mainly making use of the FT-Raman system.

In Stage 1 Deakin will make use of its existing UV laser facilities to develop further UV Resonance Raman (macroscopic) on proteins, ion solvent interactions, and polymer systems. The study of cell walls and wool fibres using UVRR will await Stage 2 since it will require the microscopic facility of the micro-Raman spectrometer.

Stage 2 (1993-1994): Implementation of UV laser excitation on machine A will be accomplished by the transfer of UV laser expertise (and possibly equipment) from Deakin to Melbourne. Once this is completed machine A will be capable of micro-UV Resonant Raman spectroscopy; a facility which will be unique in Australia. The expertise developed at Deakin in macro-UV Resonant Raman spectroscopy will then be applied to a range of biological and biochemical problems for which micron-scale resolution is necessary and the projects in plant biotechnology, and wool fibres will proceed as well as studies involving Raman mapping of cells.

It should be stressed that although both machines A and B will have micro capabilities, both machines will, of course, still be capable of

macro analysis, and as mentioned above even when micro scale spatial resolution is not required, microspectroscopy often has the advantage of reducing fluorescence and increasing sensitivity.

In the 1993-1994 time scale the two equipment developments mentioned in Section 5.5 - Confocal Raman Microscopy and Raman mapping will be implemented.

It should be stressed that at all stages students and staff from any of the three participating institutions will have ready access to both machines.

7. MANAGEMENT

The management of the facilities will be in two tiers. Everyday running and scheduling will be carried out by the local institution. The Melbourne machine will be managed by the Micro-Analytical Research Centre (MARC) situated in the School of Physics at the University of Melbourne. As its name implies microanalytical research is at the centre of MARC's interest and operations. To date the research has focused on applications of proton beams for analysis, but the exclusion of reference to nuclear techniques on the Centre's title is indicative of a willingness to expand into other areas of microanalysis. MARC was set up to provide a visible interface between a major facility (proton microprobe) and industry. MARC is recognised internationally as a leader in its field and performs and continues to perform analytical work for a wide range of industries (minerals, metals, materials, agriculture, radiation safety, forensic science and drug research) as well as its varied scientific collaborations. MARC's experience and success in the management of a large complicated facility indicates that it is well qualified to take on the management of a new microanalytical facility - the Raman microprobe. Combining the compositional information available from the proton microprobe with the structural information available from the Raman microprobe presents the possibility of the development of an extremely powerful, new, hybrid imaging technology. The Director of the Centre is Dr George Legge, but the running of the micro-Raman facility will be the responsibility of Dr Steven Prawer.

The equipment at Deakin would be part of a central instrument laboratory operated as a University facility. The details of this facility are still being worked out but it is expected that the manager of the laboratory will be a professional officer Mr E Mocellin, and he will assume overall management responsibility for the equipment. It is also expected that an academic staff member will be given specific responsibility for the new spectroscopic equipment. Professor James will be involved but will delegate management responsibility.

The three partners will however maintain overall management responsibility for the operation of both instruments and ensure that the primary goal of providing access to micron-scale, optical measurements is maintained. Quarterly meetings will be held to monitor progress and review financial considerations.

A free flow of samples and personnel amongst the three institutions is expected. A particularly attractive aspect of this proposal is that it offers enhanced opportunities for interchange between chemists, physicists, biologists, chemical engineers, geologists and materials scientists, and offers expanded opportunities for post-graduate student interaction.

7.1 TECHNICAL SUPPORT

Experience has shown that facilities used by a large number of scientists from a wide variety of backgrounds require dedicated technicians to train new users in the safe and effective operation of the equipment. Both machines A and B are turn-key systems and maintenance requirements should not be too onerous. Nevertheless, in order to provide effective service to all users, at least one half-time technician will be required at each facility. Deakin University has agreed to provide this level of technical support for one machine. A budget item in this proposal is for the provision of a technician for three years to be assigned to install and commission the micro-Raman spectrometer and to train new users. Without this level of technical support the goal of providing access to the widest possible range of users may be compromised. At the expiry of the three years we expect to be able to support a technician from ARC grants of the combined partners.

7.2 COST SHARING

There will be no attempt to recoup the capital cost of the equipment. However maintenance of the equipment will require

1. Periodic replacement of laser tubes (~\$20,000 per annum).
2. Contribution to support staff salaries (~\$20,000 per annum).
3. Miscellaneous consumables, replacement parts etc (~\$10,000 per annum).

To cover these costs, charges for the use of the facilities will be levied at approximately the following rates:

1. \$30/hour for partners
2. \$50/hour for outside university users
3. \$100/hour for industrial users.

These rates are modest if it is taken into account that as many as 100 spectra can be recorded in a typical working day and so outside users may only require a few hours of machine time to get the answers they need.

8. FINANCE

1992 COSTS:

Purchase Costs:

| | |
|------------------------------------------------------------------|------------------|
| Machine A - UV/VIS micro-Raman, plus heating and freezing stages | \$390,000 |
| Machine B - FTIR, FT-Raman with microscope attachment | \$280,000 |
| Technical Assistance | \$50,000 |
| Total Cost (1992): | <u>\$720,000</u> |

COMMITMENTS FROM INSTITUTIONS:

| <u>Institution</u> | <u>Cash</u> | <u>In-Kind</u> |
|--------------------------------------------------------|--------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| University of Melbourne | \$50,000 (Fac. Science) \$50,000 (Univ. Melb. Central Funds) | MARC Administration and Secretarial (\$20,000) Technical Support (General) Space Cryostats |
| Deakin University | \$70,000 | Argon Laser (\$30,000) †Half-time Technical (\$25,000) UV Lasers (>\$100,000) |
| Monash University | \$10,000 (Physics) | Argon Laser (\$30,000) Part-time Technical (\$20,000) Cryostats (\$15,000) Existing macro-Raman spectrometer with in-situ four-point bending facility (\$25,000) High Pressure Diamond Anvil Cell (\$15,000) |
| Victorian Institute of Earth and Planetary Sciences | \$10,000 | - |
| CSIRO Division of Materials Science and Technology | \$20,000 | - |
| | <u>\$160,000</u> | <u>\$280,000*</u> |

Further contributions are being sought from Telecom (\$15,000) and ICI (\$10,000), the Australian Pulp and Paper Institute.

SUMMARY 1992:

| | |
|-----------------------------------------------------------|------------------|
| Total Cost: | \$720,000 |
| Less cash Contributions from participating organisations: | \$210,000 |
| Requested from the ARC (Mech. C) for 1992: | <u>\$510,000</u> |

†Deakin University has committed a technician (half-time) to run the proposed facility.

*This is a minimum figure which includes items which are easily costed. Space, general technical support, and consumables have not been included.

1993/94 COSTS:

| | |
|------------------------------------------------------|----------|
| Technical Assistance (requested from ARC (Mech. C)): | \$50,000 |
|------------------------------------------------------|----------|

9. RELATIONSHIP OF PROPOSAL TO RESEARCH DIRECTIONS OF PARTICIPATING INSTITUTIONS

9.1 MONASH UNIVERSITY

The projects listed which are of interest to Monash University staff fall into the general category of "Advanced Materials" and are therefore consistent with the Research Policy and Management Plan for Monash University. In addition, Condensed Matter Physics has been the major research area of the Monash Department of Physics since its commencement. Raman Spectroscopy began at Monash University in 1965 as a technique for fundamental Solid State Physics and the field has produced five PhD graduates. Dr F. Ninio has been responsible for the development of the existing macro-Raman spectrometer and his expertise in the interpretation of optical spectra is significant. The thrust of Raman spectroscopy into the area of Advanced Materials Characterisation was recognised by the ARC with the award of an Australian Post-Doctoral Research Fellowship to Dr C.S. Lim in 1990, within a project under the leadership of Associate Professor T.R. Finlayson.

9.2 DEAKIN UNIVERSITY

The equipment described in this proposal will provide invaluable support to several areas identified in the university research profile. In the area of chemical science studies of materials particularly related to catalysis, the study of particulate interactions in solution, analytical support of synthetic programs and studies in occupational hygiene where analysis of dusts and aerosols are important. In the area of biological science and biotechnology the techniques will provide unique support in several important areas at both the molecular biological level and the gross solution level. These studies are also related to the applications in aquatic science which is a targetted area of research significance. As mentioned elsewhere Deakin is a partner in a bid for a centre in wool science and there are several relevant projects. Finally in the emerging engineering area a topic of importance is lightweight structures and the spectroscopic techniques will be useful in these studies.

9.3 UNIVERSITY OF MELBOURNE

The Research profile of the University of Melbourne, School of Physics, has identified Condensed Matter Physics and microanalysis as current research strengths and new materials as a potential research strength. Indeed interest in materials science is increasing in the School of Physics, which houses two major facilities, viz. the proton microprobe, and the High Resolution Electron Microscope. The former is under the auspices of the Micro-Analytical Research Centre (M.A.R.C.) whilst the latter falls under the umbrella of the National Advanced Materials Analytical Centre. The

addition of a Raman microprobe to the suite of facilities would be a major boost to the existing and emerging interests in materials science. The combination of proton and Raman microprobes would enable the synthesis of both compositional and structural determinations all on a micron scale.

10. FURTHER INFORMATION

Should the committee require further information such as Curriculum Vitae, copies of letters of support, lists of funded ARC projects, copies of quotations for the supply of the two major instruments, publication lists more detailed descriptions of the proposed management structure or any other additional information please contact the co-ordinator for this proposal:

Dr Steven Praver, School of Physics, University of Melbourne,
Parkville, Victoria, 3052.
Telephone: (03) 344 5460
Fax: (03) 347 4783

11. TABLE I - INTERESTS OF PARTICIPATING PARTIES

PARTNER:

| <u>Institution</u> | <u>Personnel</u> | <u>Materials of Interest</u> |
|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| University of Melbourne | Dr S. Praver (Physics) Dr D. N. Jamieson (Physics) Dr Ghiggino (Chemistry) | Diamonds, Diamond-Films Glassy Carbon, Carbon Fibres, HgCdTe and other semiconductors. Wool fibres, polymers. Some biological interests emerging. Techniques: Phase Identification, Crystal Quality Evaluation, Imaging. Confocal Raman microscopy. |
| Monash University | Assoc.Prof.T.R. Finlayson (Physics) Dr F. Ninio (Physics) Dr C. Lim (Physics) Assoc.Prof. J.R. Griffiths (Mat Eng) Dr I. Parker (Chemical Eng) | Ceramics (PSZ) Bone Wood Pulp High T _c superconductors. |
| Deakin University | Professor David James Professor R. Russell Mr. E. Mocellin | UV resonance Raman particularly for biochemical and biological applications. Vibrational analysis of solutions. Industrial applications of Raman spectroscopy. |

Other interested parties include:

| | | |
|-----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|
| Victorian Institute of Earth and Planetary Sciences | Dr R. Keays (Univ. of Melb.) Dr M. Wallace (Univ. of Melb.) Professor I. Plimer (Univ. of Melb.) Dr T. Kwak (Latrobe Univ.) Dr M. Bloom (Monash Univ.) | Fluid and Solid Inclusions in Minerals |
| CSIRO (Materials Science & Technology) | Dr Tim Williams & carbon-fibre project personnel Dr J. Drennan | Carbon Fibres Ceramics (PSZ) |
| Telecom | Dr Singh Goh Dr Stone | Optical Fibres MOCVD semiconductors Fluoride Glasses |