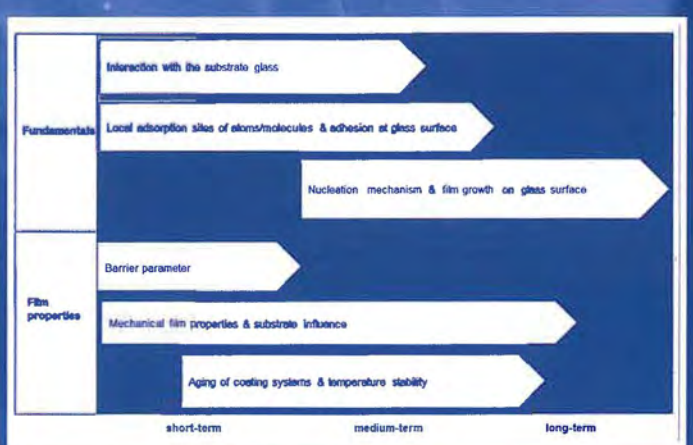
MAKING GLASS BETTER

ICG roadmaps of Glass R&D with a 25 year horizon

2nd edition

Edited by
KLAUS BANGE, ALICIA DURÁN AND JOHN M. PARKER



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ICG
International Commission on Glass

OUTLINE

FOREWORD 2nd EDITION

The International Commission on Glass (ICG) is a not-for-profit international GLASS SOCIETY comprising currently 32 national organisations in glass science and technology representing their countries, along with 4 Associated Organisations and 9 Associated Member Companies all over the world. Its main aim is to promote and stimulate understanding and cooperation between **experts** in the science and technology of glass and it has operated successfully over a period of more than 8 decades.

Its objectives are achieved through the activities of its Technical Committees (e.g. laboratory round robins, comparative studies, topical meetings), which in turn create the scientific and technical "backbone" underpinning all other actions including: a) the compilation of information on glass e.g. the publication of scientific and technical papers, reports and books, and b) the sharing and dissemination of knowledge on glass through advanced educational courses and workshops. A further major role is to organise international meetings and conferences, which are also based mainly on the expertise of the Technical Committees (TCs).

Major benefits are gained from the direct association between international glass experts in the fields of science and technology and through liaisons with related fields of technology such as optics, photonics, electronics, nanotechnology, coating technology, biotechnology, polymers and composites. The Coordinating Technical Committee (CTC) monitors and coordinates the TC activities and one of the main tasks of CTC is to maintain the currency of its organisation and in particular the R&D topics. Therefore in 2006 the CTC discussed, developed and prepared a specific **Road Map** exercise for the ICG. The kick-off event in the ICG Road Mapping process took place in Strasbourg in 2007, at the XXI International Congress on Glass. Several road-mapping workshops followed, covering the most important R&D fields. The results were documented in the 1st edition of this booklet in 2010 and led to a reorganisation of the TC cluster structure and the creation of new TCs.

Since the speed of change in the fields of science and technology of glass has not decreased, the road mapping process could not stop in 2010 – continual revision is required as our knowledge base expands and as new pressures arise. New roadmap workshops with invited experts have been arranged and the main results are summarised in this booklet. Seven new sections are included and also the existing material of the 1st edition has been critically reviewed.

We hope and wish that this 2nd edition, which tries to identify the most relevant activities in our fields for the next decade and to promote the necessary fundamental research, will stimulate discussion and create a solid basis for future measures. The pre-competitive character of such activities will improve the cooperation among countries and companies through the ICG global platform, helping to make our material, glass, attractive and promoting the adaptation of education to the future needs of our various societies.

May 2014

Peng Shou
ICG President

EDITORIAL

Klaus Bange, Alicia Durán and John Parker

WHY THE SECOND EDITION NOW?

The 1st edition of MAKING GLASS BETTER appeared in 2010 and now we are publishing a 2nd edition just 4 years on – this seems to be a rather short gap for a material which is 6000 years old and has an extended tradition. But the role of glass is changing – a paradigm shift seems underway and seismic changes are in progress, driven, for example, by new opportunities in the biomedical field, environmental factors and a rapidly changing energy market.

In many traditional glass products, e.g. container (bottles) or tableware (drinking glass), the material and its role are clearly recognisable. The markets are stable and they are commodity products today. Yet an essential issue in the production of glass has been and continues to be the development of new melting processes that promote energy saving and diminish emissions to the atmosphere, reinforcing the concept of glass as an eco-friendly material, the only fully recyclable material in the demanding concept of recycling. Evolution and revolution are the routes open to travel in this area. In other traditional uses as glazing, flat glass is surface modified to provide new and amazing applications not imagined a few decades ago. Even so, environmental pressures are driving R&D and demand innovative thinking.

In modern glass applications, e.g. in the IT area, in energy technology glass plays more and more the role of an *enabling* material (in particular in combination with its surface features). Often the glass is unrecognisable in the final product – but the product cannot be made without glass. Another key field that of optics and optoelectronics, is boosting the evolution of glass and glass-ceramic products for frontier technologies. These "new" applications often require very specific glass properties, characteristics that have to be created and optimised.

The ICG operates as a platform for exchange between glass scientists and promotes cooperation in glass science and technology. To realise this mission and maintain the currency of its activities, the ICG (and its acting arm, the CTC) must monitor continually the glass research field and perceive the most important trends. Often in the past, discussions, and other similar activities, on future glass science and technology have not been documented systematically; consequently key results may have been lost. To solve this problem the ICG has developed an organisation-specific roadmapping process in which it invites regular experts – often TC chairs or TC members, but also external experts - to roadmap workshops on selected topics. Most of the new results from such workshops in the period from 2010 to 2013 are documented and published in this booklet.

The 1st edition formed a solid basis for: a) an exchange of opinions concerning the future directions of glass research and b) an appropriate prioritisation of research topics. Its impact was immediate. For example the conclusions initiated dramatic changes in the TC structure of the ICG: new TCs were installed; some TCs merged; others, having completed their tasks or reached the end of their useful life, were closed while some TCs changed the direction of their research or added new activities. Besides the successful resolution of these internal structural issues within ICG, most participants

provided positive feedback on what they had gained from the workshops. For example, many were surprised by the learning outcomes which resulted from the systematic approach used, including specifically the focussed exchange with other experts on individual topics. Several TC members commented on the valuable overview of glass R&D required for future progress. Some academics intimated that the booklet provided an invaluable guide to topics that should be considered as part of their normal curriculum development process. Since the ICG concentrates on precompetitive research, some industrial participants commented that they would have liked more on application-related activities.

WHAT IS NEW?

Those members of the CTC who are also coordinators of a TC cluster have been responsible for the **review process** for the respective chapters in the 1st edition which related to "their" cluster. Each analysed the existing material within their chapter in cooperation with other experts and produced a review which is printed in this booklet.

The evaluation process was based on specific questions e.g.:

- What is missing? (New topics on the horizon? Is an update of the R&D field needed?)
- What has changed? (Changes in prioritisation, in the time line...)
- Are the R&D topics still relevant today (2013) for glass?

Using this procedure the following additional sections were created:

- 3.1.1.4 Review of Sect. 3.1.1 "Glass melting technology - an overview"
- 3.2.4 Review Sect. 3.2 "Materials for technical and medical application"
- 3.3.1.4 Review Sect.3.3.1 "Basic glass science – an overview"
- 3.4.1.5 Review of Sect 3.4.1 "Glass surfaces & stress corrosion mechanisms"
- 3.5.1.4 Review of Sect 3.5.1 "Applications – an overview"

The main new contributions in the 2nd edition are documentations of the results of ICG roadmap workshops, some of which were carried out partly in cooperation with other scientific organisations. The same style and format as in the previous booklet has been used for seven **new sections** which are:

- 3.1.2 Applications of sensors and advanced process control
- 3.1.3. Fining/refining
- 3.1.4 Energy efficiency in melting process
- 3.1.5 Innovation in glass production
- 3.3.2 Structure and vibrations in oxide glasses
- 3.4.2 Glass surfaces and thin films on glass
- 3.5.2 Glasses for pharmacy
- 3.6 Summary of the results of the roadmap activities

All these sections are highly specific and contain much rich detail; the contributing experts are named at the end of the booklet.

HOW TO USE THE BOOKLET?

The roadmaps developed and shown here should not be used as a "bible" for a given R&D field. They represent only a simplified version of a complex reality. But, since a reduction of complexity is one of the scientific tools that is important in gaining a better understanding of a complex matter (as long as the most relevant variables or most influential parameters are not lost), roadmaps are accepted worldwide as a sound basis for serious discussions on specific R&D topics. This is particularly so since in general they are created in cooperation with the experts in the respective field. Roadmaps are therefore innovation planning tools which provide a prognostic view on future developments through a systematic collection and validation of expert knowledge. The main benefit of the roadmapping process is that it provides the specific information and options needed to generate active measures.

The concept behind the publication of this second edition of Making Glass Better is to contribute to the building of a scientific and technological atlas in the field of glass which will help both scientists and the glass industry find the most fruitful routes to extend the catalogue of glassy materials and to uncover new applications.

We hope that this 2nd edition of this book of maps will stimulate fruitful discussions on future research into our fascinating material glass both inside and outside the ICG, and will attract excellent scientists and technologists to join our community.

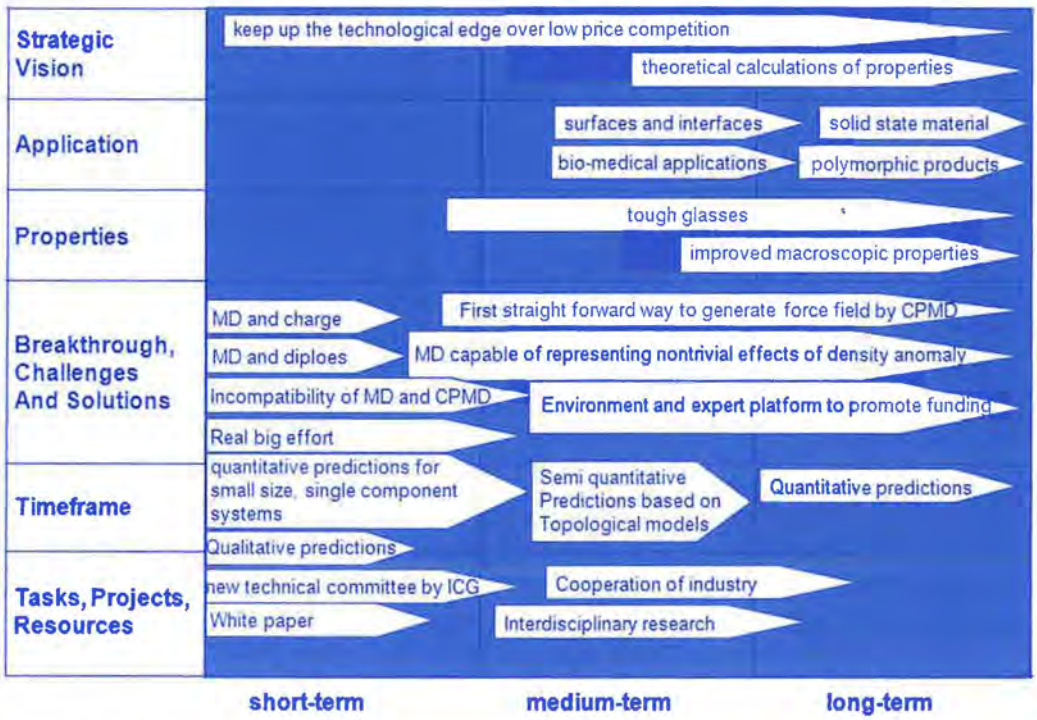

Figure 3.3.1.3: Roadmap "Atomistic Simulation of Glass"

This simplified overview can be used to set in motion the promotion of a collaborative research agenda for atomistic simulation of glass. An important objective is the organisational and institutional setup of this "wish list" since the objective is not to produce yet another report but to implement a living process carried by the community itself and the commitment of a handful of key actors. A first step was to establish a new technical committee in the ICG (TC27 was established in June 2009 in Vancouver) and the plan to generate a white paper which serves as an in-depth definition of the tasks. A follow-up workshop, based on the described results is planned by TC27 in May 2010 at Corning, USA.

3.3.1.2.5 Properties of glass

One important cluster for research is the development of glass products integrating multiple functions in one material. These functions can be optical (351), mechanical (348), electric and dielectric (354), thermic (357), glass-gradients (360), light-weight (361), improvement of chemical (362) properties. Mechanical and light-weight glasses were rated as of highest relevance. A long-term task is the integration of a combination of functions in one material and not isolated research for one property. The research is expected to be undertaken as joint funding by private and public agencies.

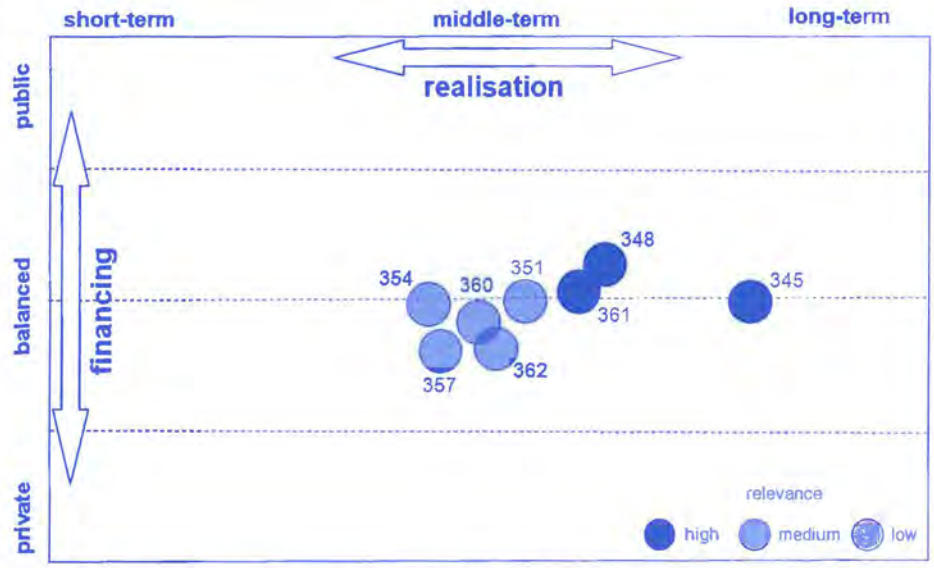

Figure 3.3.1.4: New Functions and Properties of Glass: Cross-Cutting

3.3.1.2.6 Characterisation

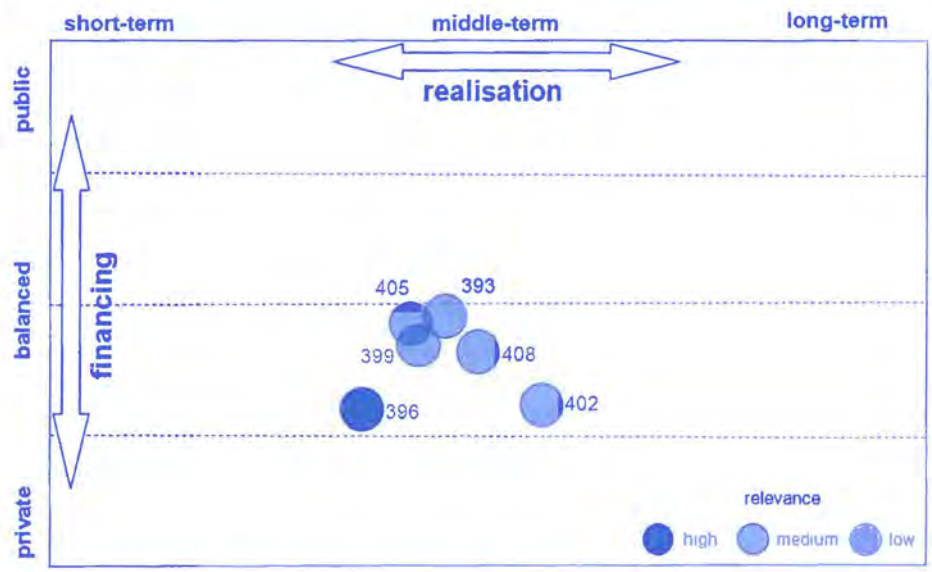

Figure 3.3.1.5: Analytics: Measuring, Testing, and Characterising

Research tasks in the field of analytics, measuring, testing and characterising were the development of cheaper tools (393), in-line diagnostics (396), in-line sensors (399), integration of stable in-line sensors into the entire production process (402), tension sensors for glass parts (405) and validation of in-line test data for the main variables (408). However these tasks are seen as to be financed by private companies since they are more or less product and process specific.

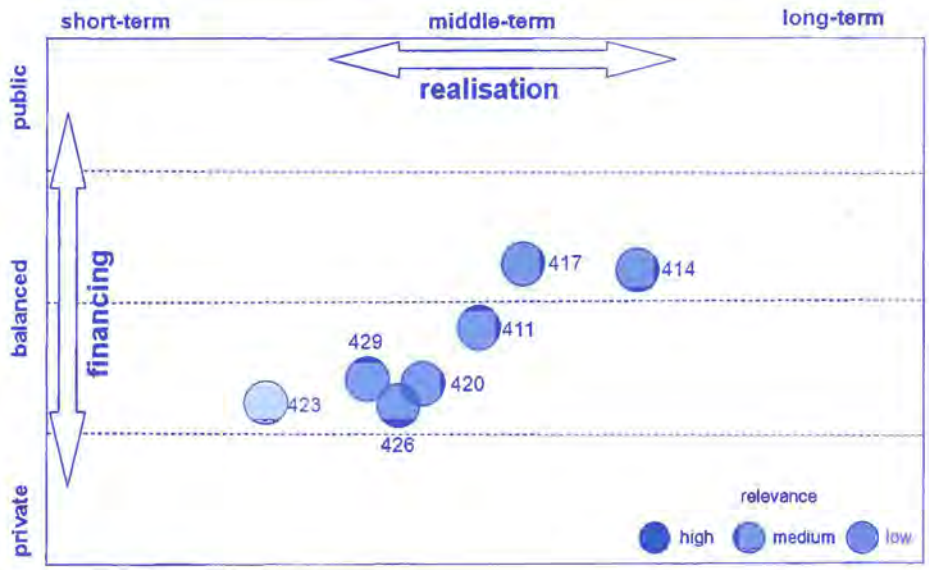

Figure 3.3.1.6: Analytics: Modelling and Simulation

In the field of modelling and simulation synergies were: finite-element calculation for glass parts (411), scale independent virtual material design (414), fundamental understanding and reliable data pools for relevant processes (417), modelling of melters (420), improvement of understanding of change of environmental influences into the models (423), models of the cooling (426) and firing (429) processes.

3.3.1.3 Outlook

The presented results serve as the basis for further discussion and prioritisation. When one of the topics is identified it needs further definition and future steps. However, at this point it is not sufficient to talk about technological issues. A roadmap is supposed to cover all aspects to facilitate technology transfer into future applications. To a considerable extent, this holds true even for basic research at the very beginning of the research chain where potential future applications or marketable products are decades away or where the risk that the generated knowledge never reaches markets is very high. The first consideration is why technological progress is necessary at all and where the future challenges lie. But an innovation system is also dependent on surrounding institutions which supply knowledge, skilled labour or influence research activity by changing regulation. These more general aspects are discussed in greater details in Chapter 4.

3.3.1.4 Review of "3.3.1 Basic glass science – an overview"

Alicia Durán, John Parker, Klaus Bange and René Vacher

The original chapter summarised the results from very different ICG activities, mainly contributions from: a comprehensive workshop on **"Basic Glass Science"** which took place in Montpellier, France in May 2009, and a project on glass perspectives sponsored by the German Research Society (DFG).

Experts discussed a wide spread of topics ranging from structural aspects to the glass transition, and relaxation to vibration-related phenomena; they also considered mechanics, thermodynamics, atomistic simulation of microscopic glass structure and macroscopic properties, glass surface features and coatings, so completing a broad overview of basics in glass science. The information obtained by the roadmap process applied in Montpellier was classified under four headings: **"Coatings"**, **"Nano-mechanics"**, **"Thermodynamics"** and **"Simulation"** and each field was evaluated during the workshop. Most of the participants ranked **"Simulation"** as the most important topic, and so it was treated in greater detail in Section 3.3.1.2.4.

Additional and very valuable results for this chapter were derived from the DFG project which addressed the fundamental aspects of glass research using interviews and questionnaires. The DFG financed the project, which was carried out by iTM (University of Kassel) in close collaboration with ICG. The results of the statistical evaluation presented in this section required the creation of two additional fields **"Glass properties"** and **"Characterisation tools"**. The most relevant topics within the various fields were discussed in the six sections of the chapter.

The different approaches used created a comprehensive but complex picture of the needs and requirements in **"Basic Glass Science"**. While in the interviews (with a higher proportion of the expert participants coming from industry) the short-term topics and more applied issues were the main focus, most of the results from the Montpellier workshop were centred on longer term issues of a more general nature.

The pearl in the chapter was the detailed evaluation of the topic **"Atomistic Simulation of Glass"** which not only reported the discussions and data presented in the workshop; but also was an excellent example of how an integrative roadmapping process can be initiated and demonstrated how complex fields can be structured, simplified and prioritised. The resulting overview has since been used to set in motion a collaborative research agenda for atomistic simulation of glass. An important organisational first step was to establish a new technical committee (TC27) within the umbrella of ICG. The results from other fields have also generated fresh actions and new TCs, strengthening tremendously the ICG cluster on "*Basics*". For example TC03 and TC22 have re-combined, TC03 has applied sophisticated measurement techniques (variants of NMR, diffraction) with thermodynamics and has undertaken several Round Robin tests to improve methodologies, while TC26 (Vibrations) has subsequently arranged its own expert meetings to progress its stated goals.

3.3.2 Structure and Vibrations in Oxide Glasses

Bernard Hehlen and Klaus Bange

An expert meeting on **"Structure and Vibrations in Oxide Glasses"** took place in Montpellier from March 24th-25th 2011. At the beginning, the organiser (Bernard Hehlen) explained the structure of and the procedures to be adopted during the workshop. The two days were divided into four sessions with the headings:

- Optic modes in oxide glasses - Simulations
- Optic modes in oxide glasses – Spectroscopy
- The boson peak - Theory and simulations
- The boson peak – Experiments