The ultrastructural control of materials through sol-gel processes offers significant promise for the achievement of reliable performance in ceramics, glass and composites. Several examples of new structural, optical and electromagnetic materials with superior and unique properties are presented based on maximal homogeneity or heterogeneity attained through understanding of the fundamental chemistry. New concepts such as ceramic molecular composites and optically active gels have been derived through polymer, physical and synthetic chemistry. Scaling calculations based on molecular orbital calculations for prediction of the silanol polymerization mechanism, and hierarchical clustering predictions for the sol-gel derived ultrastructures are presented. The application of polymeric network theory to the design of gel ultrastructures is presented.

INTRODUCTION

Modern glass and ceramics have been the products of applied physics approaches, which have produced advances in ceramic science for the past four decades. The emphasis of these approaches has been on structural development at the microstructural level (>10,000Å), property control through establishing the relationships between physical behavior and microstructure, and densification through high temperature and fabrication technologies. However, these approaches alone, based on high temperature and sophisticated fabrication technologies, still impose a severe limit on producing ceramics, ceramic composites and glasses of high reliability, particularly for use in severe environments. They do not control the variabilities arising from the physical chemistry of the materials which lead to unpredictable, catastrophic failures during use; and which inhibit the attainment of properties approaching the theoretical values in structural, electronic and optical ceramics, glass and ceramic composites.

As shown in Fig.1, the major advances in ceramics and glass required to attain the aforementioned objectives during the next 20 years will depend on an approach which emphasizes control through all aspects of the chemistry. This approach is called ultrastructure processing. Since 1978 the U.S. Air Force basic research program has focused on the chemical
Fig. 1 Changes in the role of physics and chemistry as ceramics moves toward ultrastructure processing.

Fig. 2 The impact of ultrastructure processing on ceramic performance.