ELECTRICAL CHARACTERIZATION OF Na₂O-CaO-P₂O₅-SiO₂-Al₂O₃ GLASS

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Hench found that some glasses in the system of Na₂O-CaO-SiO₂-P₂O₅ show bone-bonding ability, i.e. bioactivity.¹ Kobayashi et al. developed CPSA glass in the system of CaO-P₂O₅-SiO₂-Al₂O₃ can be formed into thread by spinning, and maintains high mechanical strength for a long period in a body environment.² Yamashita³ ⁴ et al. developed electrical polarization as a new technique to regulate the process of the bonding with the host tissue and the bioactivity of biomaterials. Electro vector effect is based on moved carrier ion. BG contained Na⁺ ion was prepared polarizability Na₂O-CaO-P₂O₅-SiO₂-Al₂O₃ glass compound made up component of BG and CPSA glass was named NCPSA glass.

In this study, it evaluated the electrical polarizability of a NCPSA glass by thermally stimulated depolarization current (TSDC) measurement, and complex impedance measurements.

NCPSA glass composed of Na₂O: 1.00, CaO: 15.75, P₂O₅: 11.85, SiO₂: 45.55, and Al₂O₃: 25.95 wt%, was prepared using reagent grade powder of Na₂CO₃, CaCO₃, CaHPO₄·2H₂O, SiO₂, and Al(OH)₃. The mixed powders were melted in a platinum crucible at 1500°C for 3h in air. To produce the glass, the melted materials were poured into a graphite mold and then quenched to room temperature. The glass annealed in an alumina crucible at 800°C for 4h. NCPSA glass were formed a quarter of disk at 8.5mm~1mm by diamond saw, and polished with diamond sequential polishers of 30, 15, and 6 μm grain sizes. The glasses with a pair of platinum electrodes put on both sides.

The complex impedance measurements were made at frequencies within the range of 10⁻²~10⁻¹ Hz and at temperatures between 50°C and 750°C. The samples sputtered with Pt electrode were clamped between a pair of Pt films and electrically polarized in a d.c. field. Polarization condition was 2kV·cm⁻¹ of d.c. field at 600°C for 60 min. The stored NCPSA glasses were estimated by TSDC measurements were repeated three times.

Arrhenius plots from the results of a complex impedance analysis showed a shift in ionic conductivity of NCPSA glass. From the measurements at a given temperature in the complex plane (Z" vs Z''), a portion of a semicircle, which we have shown to be characteristic of the electrolyte was formed. The impedance at each temperature was found with the circle radius that was measured from the extrapolated arc in the plots. One semicircle was obtained in the Z" vs Z' plots. At temperatures approximately between 505°C and 750°C. This indicated that the ion conduction process of the NCPSA glass was due not to some sources, but only to the bulk of the material because of the glassy phase of the material. The bulk ohmic resistance relative to each experimental temperature is the intercept on the real axis of the zero phase angle extrapolation of the highest frequency curve for the electrical conductivity (σ) in Table 1. Electrical conductivity of NCPSA glass of 505, 554, 602, 651, 700, and 750°C were 1.79×10⁻⁹, 6.32×10⁻⁹, 1.41×10⁻⁸, 2.71×10⁻⁸, 5.78×10⁻⁸, 1.10×10⁻⁷ S·cm⁻¹.

The temperature dependence of σ approximately between 505°C and 750°C is given in Fig.1 as a plots of σ vs. inverse temperature. The σ vs. 1000/T plots gave one straight line that revealed an activated mechanism of electrical conduction, based on Arrhenius' law
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Table 1. Electrical conductivity of NCPSA glass

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>σ (S·cm⁻¹)</th>
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<tbody>
<tr>
<td>505</td>
<td>1.79 × 10⁻⁹</td>
</tr>
<tr>
<td>554</td>
<td>6.32 × 10⁻⁹</td>
</tr>
<tr>
<td>602</td>
<td>1.41 × 10⁻⁸</td>
</tr>
<tr>
<td>651</td>
<td>2.71 × 10⁻⁹</td>
</tr>
<tr>
<td>700</td>
<td>5.78 × 10⁻⁹</td>
</tr>
<tr>
<td>750</td>
<td>1.10 × 10⁻⁷</td>
</tr>
</tbody>
</table>

$$σ = A \exp\left(-\frac{E_a}{kT}\right)$$

In this law, Ea is the activation energy and k is Boltzmann's constant. The σ vs. 1000/T plots indicated the existence of a activation energy of the electrical conduction as Ea =1.4eV.

![Arrhenius plots of NCPSA glass](image)

The TSDBC spectra showed that the depolarization of the NCPSA glass. The maximum peak of the depolarization current density decreased from 64 to 9 μA·cm⁻² with an increase of the times from once to three times (Fig.2). The calculated the dissipated current of the NCPSA glass electrically polarized in the dc fields of 2kV·cm⁻¹ were 4.91, 2.73, and 0.34 mC·cm⁻², respectively.

![TSDC spectra of NCPSA glass](image)

In this study, NCPSA glass had an electrical polarizability, indicated by appearance of peaks on TSDBC spectra, and was able to store large electrical charges. The depolarization charge of NCPSA glass polarized in a d.c field of 2kV·cm⁻¹ at 600°C for 1h was 4.91 mC·cm⁻². On the other hands, the depolarization charge of HAp polarized in a d.c field of 1 kV·cm⁻¹ at 300°C for 1h was 4.2 μC·cm⁻². NCPSA glass gained a 1000 times greater polarization charge application in comparison to HAp. Furthermore, It is thought that NCPSA glass is slowly depolarization material from TSDBC spectra appeared by measurement of NCPSA glass was repeated three times.

In this study, we confirmed that NCPSA glass an electrical polarizability, and is able to store large electrical charges. NCPSA glass is slowly depolarization material. The large electrical charges were assumed to have the possibility to adjust each property of the biomaterial. Thus, the electrical polarization treatment should to be applicable to various biomaterials.

REFERENCES