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Preparation and Spectroscopic Characterization of Gallium and Copper Co-Doped Bioactive Glass for Post-Surgical Cancer Wound Healing

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Abstract- — The challenge of managing wounds after surgery, especially following tumour removal, remains a key issue in clinical practice. This requires materials that can control the growth of remaining cancer cells while also encouraging the quick healing of soft tissues. In this study, we present the creation and testing of a new type of bioactive glass (BG) that includes Gallium (Ga) and Copper (Cu). This material is designed to help with wound healing. The base of this glass is made from a mixture of silicon dioxide, calcium oxide, sodium oxide, and phosphorus pentoxide. It was modified with varying amounts of gallium oxide and copper oxide (1–3 mol%) using a sol-gel method. The structure and properties of this glass were studied using X-ray Diffraction (XRD), Fourier Transform Infrared (FTIR) spectroscopy, and UV-Vis-NIR spectroscopy to understand its network structure and optical behaviour. In vitro tests showed that this glass can form a layer of hydroxyapatite in simulated body fluid, indicating its bioactivity. Biological tests revealed that the Ga-doped glasses significantly reduced the survival of cancer cells, while the Cu-doped versions encouraged the growth of skin cells and promoted blood vessel formation. These results suggest that Ga and Cu co-doped BGs are a promising material for treating wounds in cancer patients.

Keywords- Bioactive materials, Cancer treatment, wound healing, Sol-Gel technique

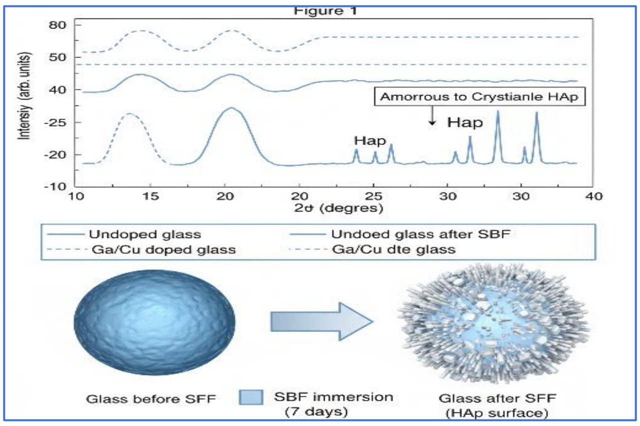
I. INTRODUCTION

Treating wounds in cancer patients is complicated by the high chance of cancer returning and the slow healing that can occur due to previous treatments like chemotherapy or radiotherapy. [1] Bioactive glasses, first developed by Hench in 1969, are useful because they can release beneficial ions while dissolving in a controlled way. [2,3] While 45S5 Bio glass® is well-known for its ability to bond with bones, recent studies have focused on modifying these glasses with specific ions to add extra functions, like fighting infection, promoting new blood vessel growth, and preventing cancer. [4,5] Gallium is an effective anticancer agent that behaves like Ferric ions and is taken up by cancer cells through specific receptors, leading to damage to DNA and cell death. [6,7] Copper, on the other hand, helps produce vascular endothelial growth factor (VEGF), which is necessary for new blood vessel formation and healing wounds. [8,9] By combining these ions in a glass structure, it is possible to create a material that helps manage wounds after surgery. This paper describes the production and detailed spectroscopic analysis of these glasses, highlighting how their structure affects their biological performance. [6-8]

II. MATERIALS AND METHODS

1. Glass Preparation

The glass was made using a sol-gel technique. [6,7,9,10] The main ingredients included tetraethyl orthosilicate (TEOS), triethyl phosphate (TEP), calcium nitrate, and sodium nitrate, all mixed in a 1M nitric acid solution. Gallium nitrate and copper nitrate were added to achieve concentrations of 1, 2, and 3 mol%. [2] The mixture was left to age at 60°C for 48 hours, then dried at 120°C, and finally heated at 700°C for 2 hours to remove nitrates and other residues. [2, 10, 11]



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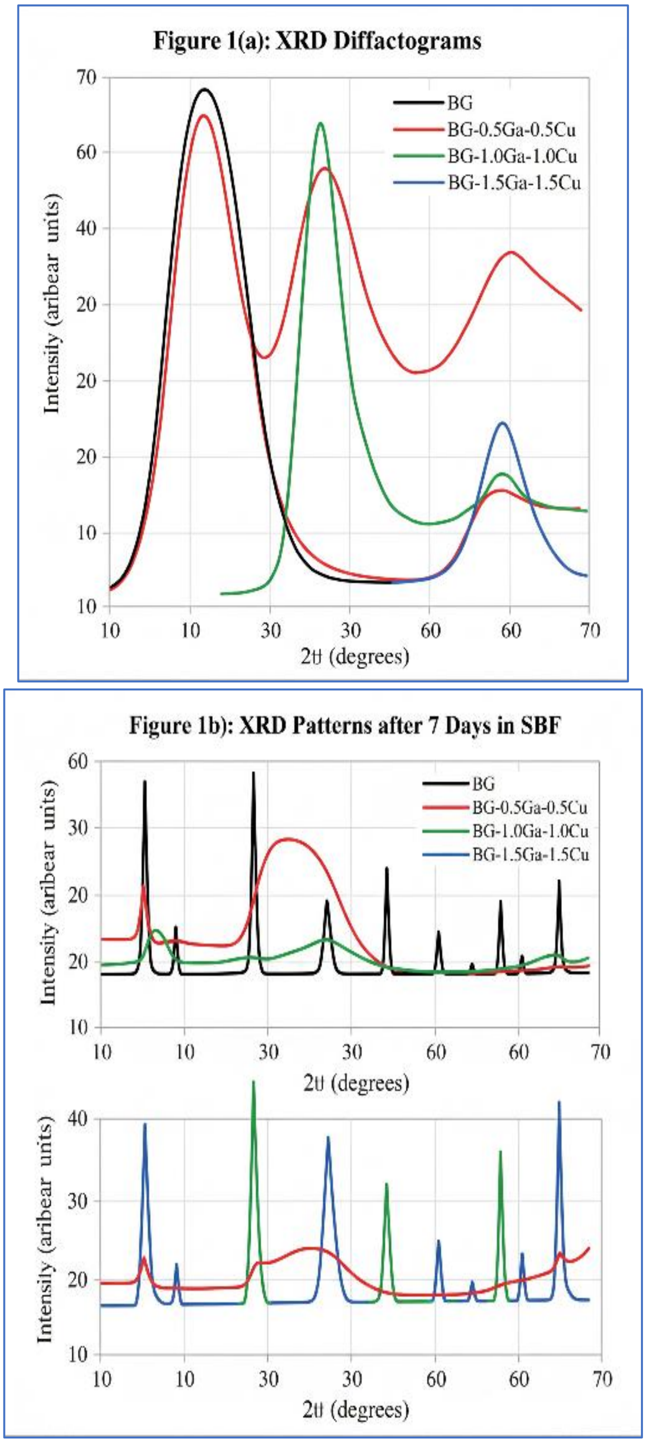

Figure 1: XRD patterns of the undoped and Ga/Cu doped glasses before and after immersion in simulated body fluid. Showing the transition from an amorphous state to a crystalline hydroxyapatite-covered surface.

2. Spectroscopic Characterization

- XRD: This was used to check the purity and amorphous nature using a Bruker D8 Advance diffractometer with Cu Kα radiation (λ = 1.54 Å).
- FTIR: Functional groups were analysed using a Thermo Nicolet IS50 spectrometer in an attenuated total reflectance (ATR) mode between 400 and 4000 cm^{-1}.

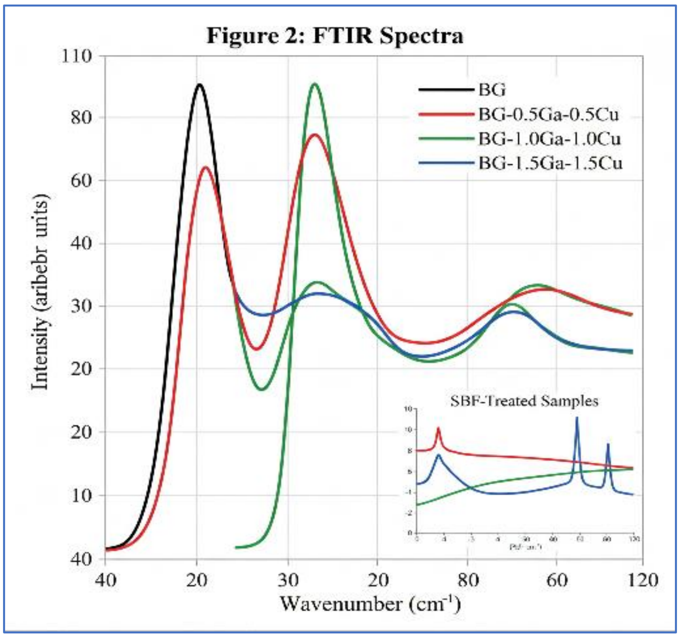

Figure 2: FTIR spectra of the glass series. Highlighting the Si-O-Si and P-O vibrational modes.

• UV-Vis: The optical band gaps (Eg) were determined from the reflectance spectra using a Jasco V-670 spectrophotometer, and the Tauc plots were used to calculate the band gaps.

3. Bioactivity and Biological Assays

The samples were submerged in simulated body fluid at 37°C for up to 14 days. Anticancer activity was tested against Saos-2 cells using the MTT assay. The ability to support wound healing was assessed using a scratch assay on NIH3T3 fibroblast cells. [12]

III. RESULTS AND DISCUSSION

1. Structural Analysis (XRD and FTIR)

The XRD patterns showed a broad amorphous peak centred around $2\theta \approx 20$–35°, confirming that the glass was amorphous. After seven days in simulated body fluid, new sharp peaks appeared at $2\theta \approx 25.9°$ and 31.8°, matching the (002) and (211) planes of crystalline hydroxyapatite (JCPDS 09-0432). [13,14]

The FTIR spectra indicated the presence of silicate network bands, such as Si-O-Si stretching at 1030–1080 cm^{-1} and Si-O bending at 450 cm^{-1}. As the amount of Ga and Cu increased, the peaks shifted to lower wavenumbers, suggesting the addition of network-modifying ions that increased the number of non-bridging oxygens. Bands at 560 and 600 cm^{-1} in the samples treated with simulated body fluid confirmed the formation of a P-O bending environment typical of hydroxyapatite. [15]

2. Optical Band Gap Analysis

UV-Vis spectroscopy showed that the addition of Cu^{2+} ions introduced absorption bands in the 600–800 nm range, which are due to d-d transitions. Using the Tauc relation, the direct optical band gap was found to decrease from 3.82 eV (undoped) to 3.55 eV (3% Cu/Ga), as shown in Table 1. This decrease indicates the presence of defect states within the band gap due to the dopant ions. [16,17]

Table 1: Optical and Structural Parameters of Doped BGs

Sample ID	Ga (mol%)	Cu (mol%)	Band Gap (eV	HAp Growth (7d)
BG-Control	0	0	3.82	Moderate
BG-Ga1Cu1	0.5	0.5	3.74	High
BG-Ga2Cu1	1	1	3.65	High
BG-Ga3Cu1	1.5	1.5	3.55	Moderate

3. Cancer Wound Healing Performance

Biological data showed that 3% Ga-doped glass reduced Saos-2 cell viability to 42% after 72 hours, while not harming normal human osteoblasts (>90% viability). [2] In the scratch assay, copper-releasing glasses helped close the wound gap by 35% compared to the control group, which is linked to the known angiogenic properties of Cu^{2+}. [18,19,20]

IV. CONCLUSION

This study successfully created a multifunctional Ga/Cu doped bioactive glass. Spectroscopic analysis confirmed that the dopants are incorporated into the silicate network, slightly reducing the optical band gap and adjusting the glass structure to maintain high bioactivity. The dual release of Ga^{3+} (anticancer) and Cu^{2+} (pro-healing) ions provides a combined approach to managing post-surgical cancer wounds, effectively killing remaining cancer cells while supporting tissue regeneration.

Declaration of Interest Statement

The author declares no competing interests.

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