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Viscoelastic and Thermoreversible study of Water-Based TiO_2 Sol-Gels for High Efficiency Photocatalytic Air Purification

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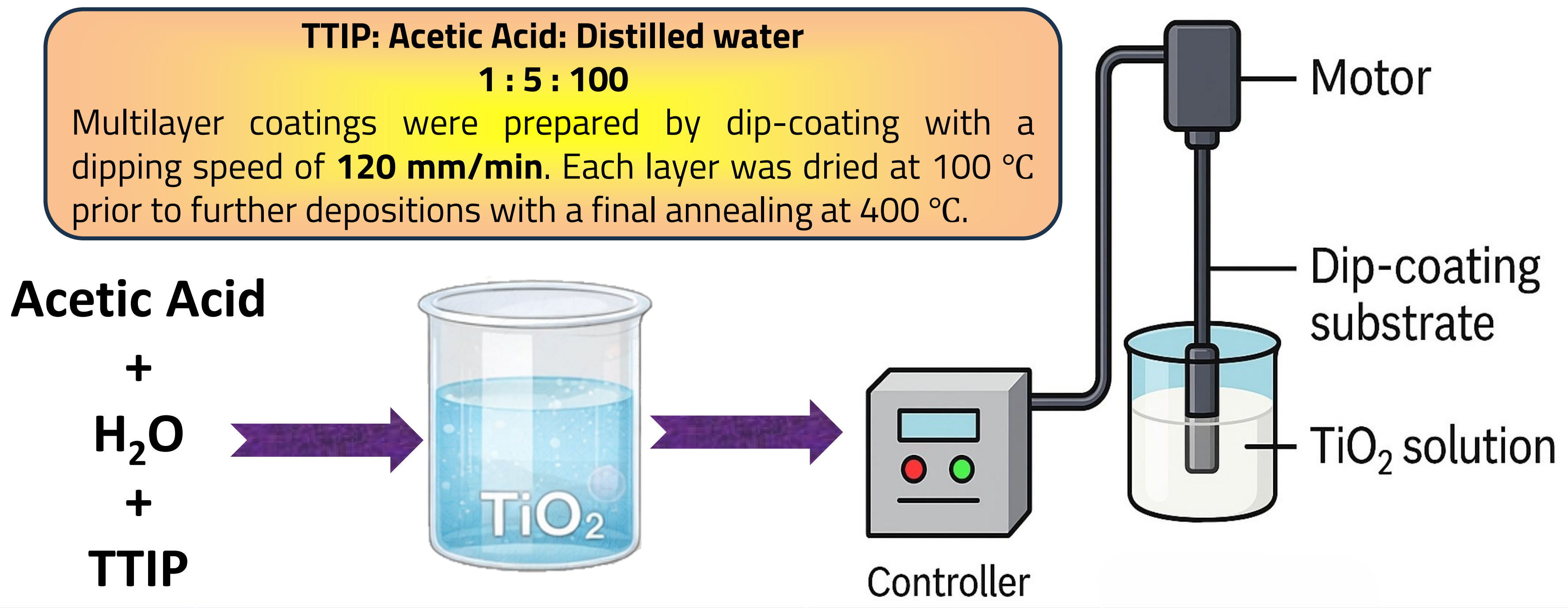
INTRODUCTION & AIM

Water-based TiO_2 sol-gels offer a sustainable route for photocatalytic coatings [1-2], but their strong hydrolysis-condensation sensitivity to temperature and aging leads to unstable viscosity, poor film uniformity, and reduced photocatalytic efficiency. These variations hinder reproducible coating deposition and limit catalyst loading, particularly for gas-phase VOC degradation [3-4].

This work aims to establish a rheology-controlled processing strategy by investigating the viscoelastic evolution and thermoreversible behaviour of aqueous TTIP–acetic acid TiO_2 sols, and to correlate sol-state dynamics with coating morphology and photocatalytic performance for efficient VOC’s degradation.

METHOD

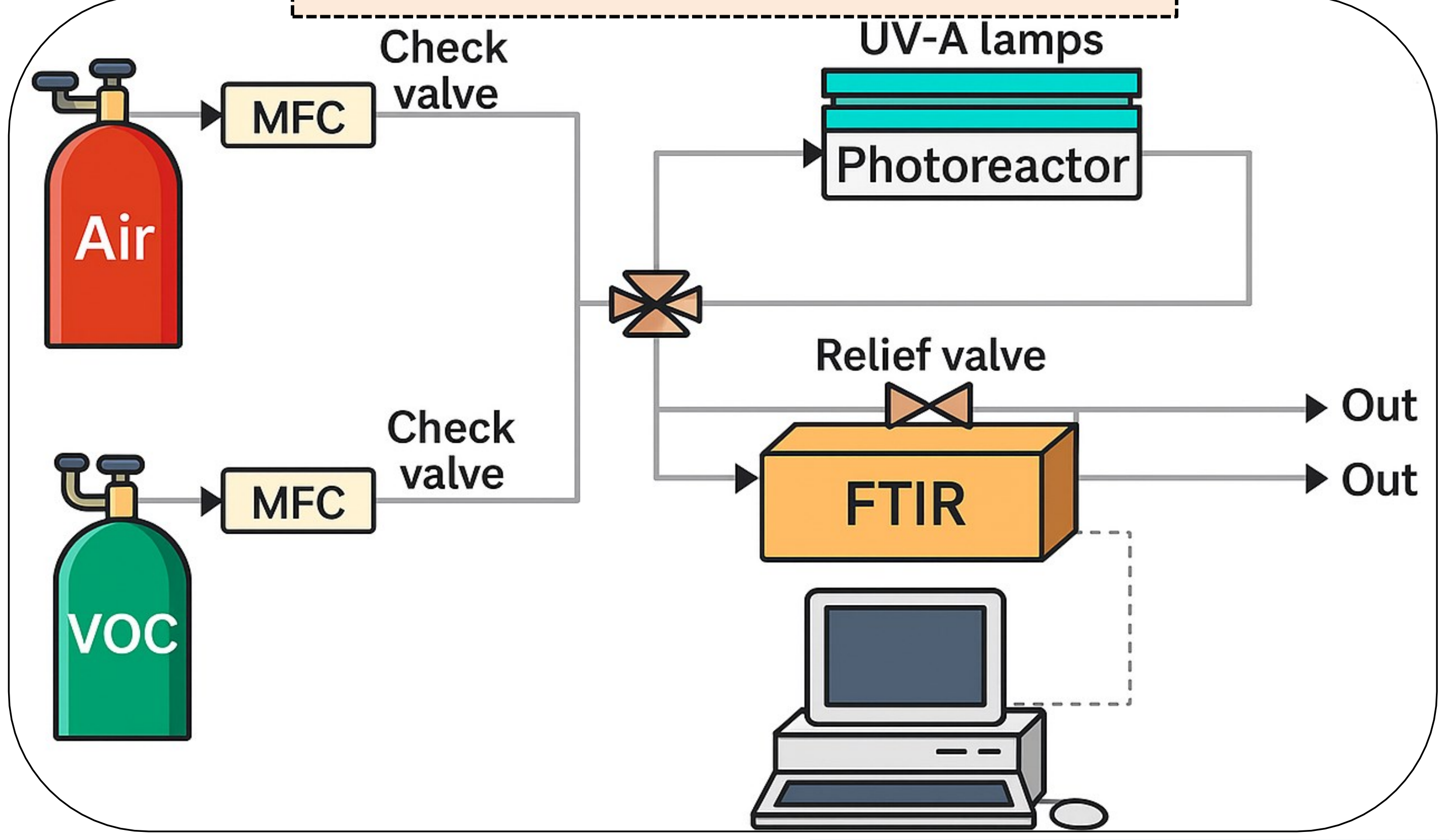


TTIP: Acetic Acid: Distilled water
1 : 5 : 100
Multilayer coatings were prepared by dip-coating with a dipping speed of **120 mm/min**. Each layer was dried at 100 °C prior to further depositions with a final annealing at 400 °C.

Acetic Acid + H_2O + TTIP

Sample ID	Sol aging condition	Density (g/cm³)	Dynamic viscosity (mPa·s)
T-a	TiO_2 sol under ambient (22-25°C) aging for 3 weeks	1.032 ± 0.002	1.62 ± 0.005
T-i	As T-a sol incubated at 50°C for 20 h and aged under ambient aging	1.025 ± 0.001	8.10 ±0.01
T-c	As T-i sol + 1 week storage at 4°C	1.025 ± 0.002	2.73 ±0.003

Gas phase photocatalytic reactor schematics



Operating Conditions	
HCHO concentration	10 ppm
UV lamp intensity	6 mW/cm²
Coatings distance from UV source	0.5 cm
UV wavelength (λ)	365 nm

VOC (X_{VOC}) Degradation efficiency: was calculated as the follow equation:

$$X_{VOC} = \frac{VOC_{inlet} - VOC_{outlet}}{VOC_{inlet}} \times 100$$

Where VOC_{inlet} and VOC_{outlet} are the concentrations of formaldehyde (HCHO) at reactor inlet and outlet, respectively.

RESULTS & DISCUSSION

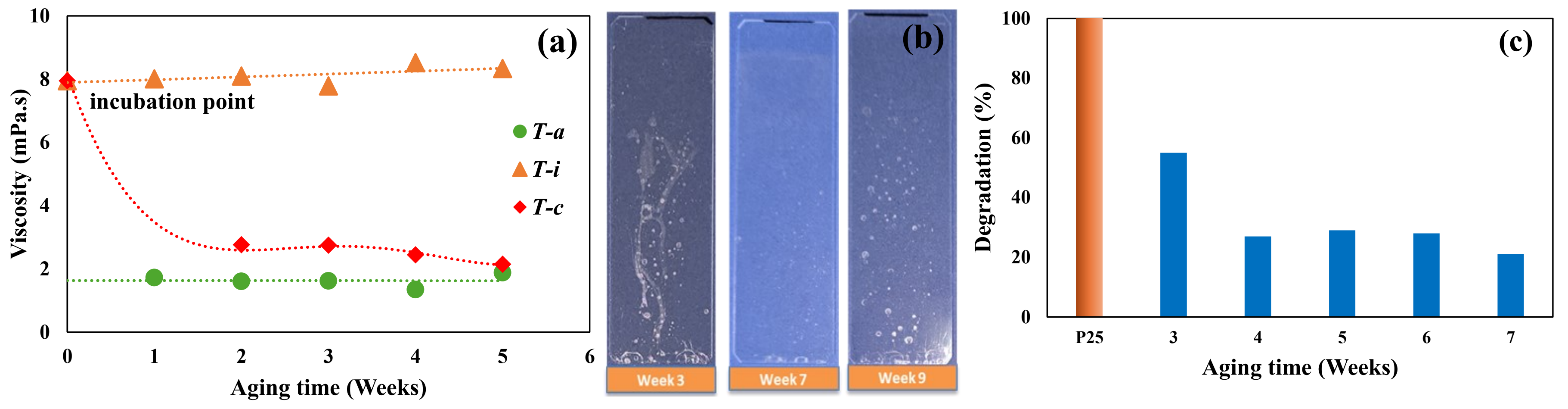


Figure 1. Viscosity profile of T-a and T-i and T-c sols over ambient aging measured by Vibro viscometer (a), T-a based coatings appearance showcasing spotted pattern of TiO_2 (b), HCHO (10 ppm) degradation efficiency of T-a based coatings (2 layers) under UV-A exposure at a flow rate 300 ml/min (c).

⇒T-a sol do not reach adequate condensation and viscoelastic development which lead to poor catalyst loading and coating uniformity resulting in poor photocatalytic performance.

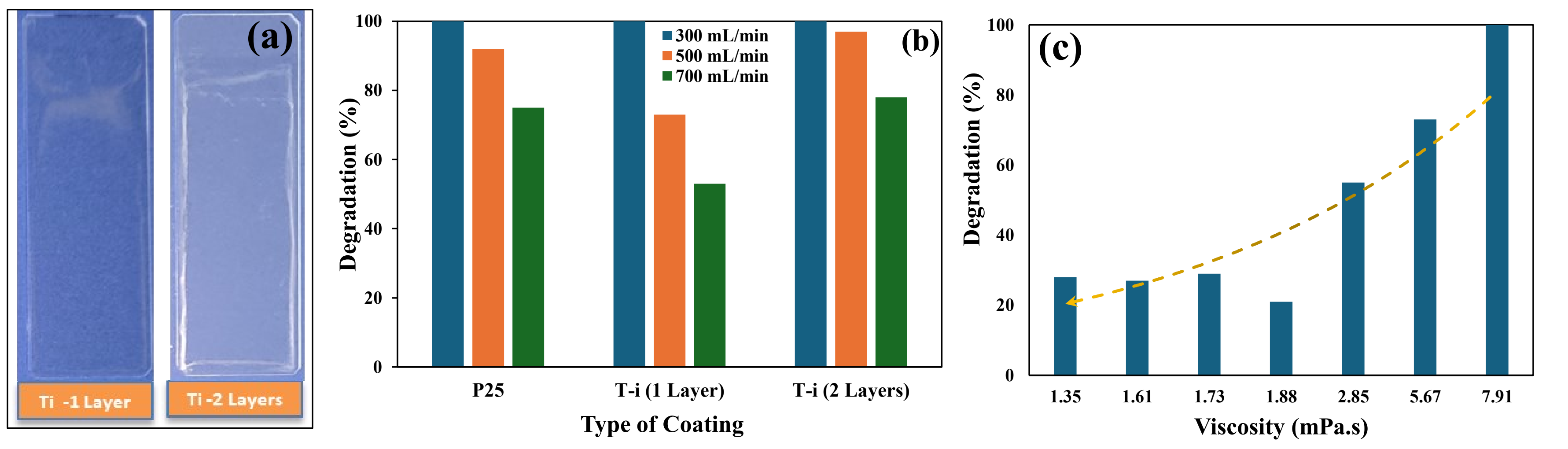


Figure 2. Appearance *T-i* based coatings showcasing uniform deposition of TiO_2 (a) and HCHO (10 ppm) degradation efficiency of *T-i* based coatings compared with 1.6 mg/cm2 of benchmark P25 under UV-A exposure at different flow rates (300-700 mL/min) (b), HCHO (10 ppm) degradation efficiency of *T-i* (7.91 mPa·s) and *T-c* based 2-layer coatings at a flow rate of 300 mL/min (c).

⇒ Thermal incubation of sol effectively overcomes the viscosity limitations inherent to water-based TiO_2 sols, yielding predictable rheological behavior, uniform dip-coated layers, and substantially enhanced gas-phase photocatalytic efficiency. While cold storage of reverses the incubation induced networking, decreasing viscosity and catalyst loading which decreased photocatalytic efficiency.

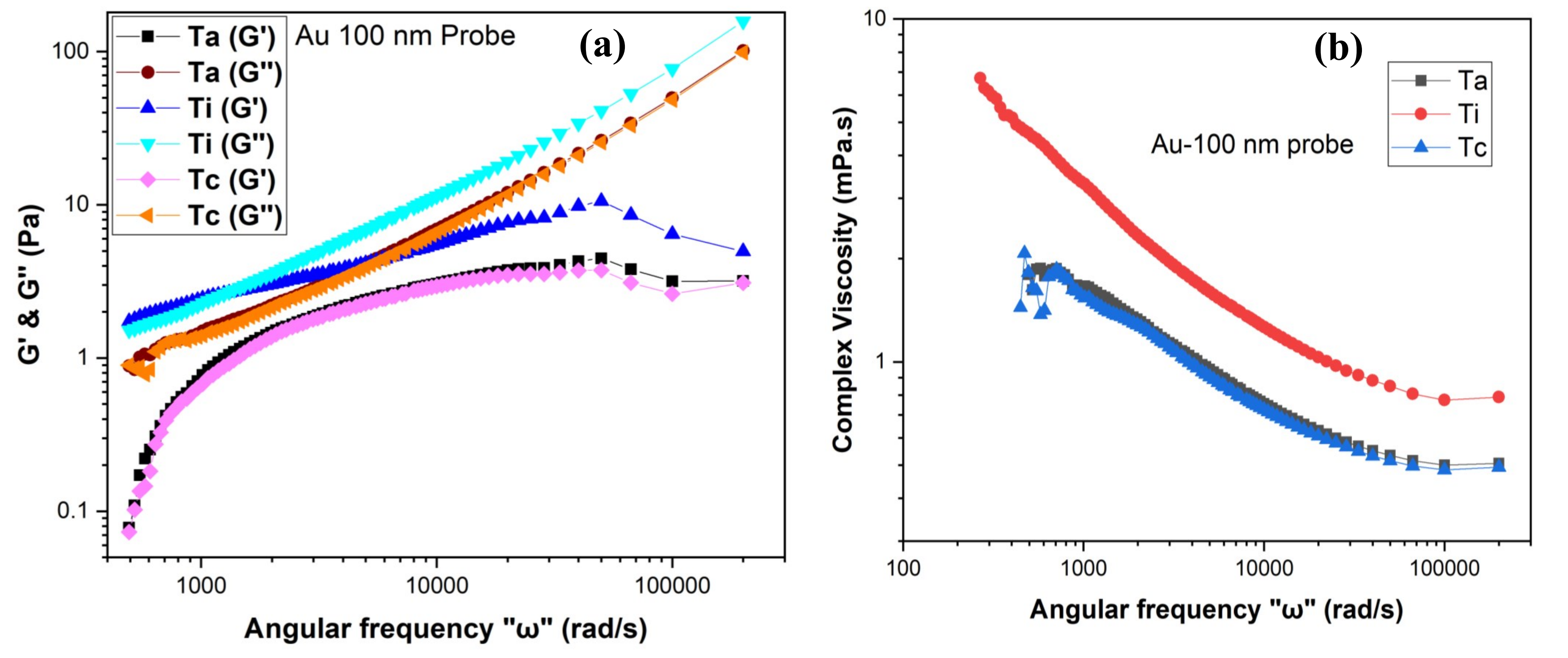


Figure 3. DLS Microrheological analysis of TiO_2 sols studied using Au probes of 100 nm (a) Storage and loss modulus of sols (b) Complex viscosities of sols.

⇒ DLS microrheological analysis confirmed higher viscoelasticity of T-i sol (higher G'/G" and η), indicating a well-developed sol-gel network. In contrast, T-a and T-c sols show weaker viscoelastic behavior, reflecting a less structured network with reduced mechanical integrity.*

CONCLUSION

Thermal incubation (*T-i*) optimizes the viscoelasticity of water-based TiO_2 sols, promoting controlled sol-gel networking and stable dip-coating behavior. DLS microrheology and viscometry confirm that enhanced viscoelastic properties yield uniform, dense, and crack-free coatings with high catalyst loading. These optimized TiO_2 coatings demonstrate excellent gas-phase photocatalytic performance, achieving up to 100% HCHO degradation under UV-A irradiation. Overall, a strong mechanistic correlation between sol viscoelasticity, coating morphology, and photocatalytic efficiency is established, offering a sustainable strategy for high-performance TiO_2 coatings.

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