



Investigations of Vacuum-UV Treatment to Maximize the Effectiveness of Organic Compounds Degradation

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Introduction

Titanium undergoes biological aging, represented by increased hydrophobicity and surface accumulation of organic molecules over time (Fig. 1), which compromises the osseointegration of dental implant. Ultraviolet (UV) treatment can decompose organic molecules on the titanium surface and enhance osteointegration (Fig. 2). Here we evaluated the efficacy of a novel ,high-energy UV light source, 172 nm wavelength vacuum UV (VUV) (Fig. 3), in decomposing organic molecules around titanium. Methylene blue solution was used as a model organic molecule placed in a quartz ampoule with and without titanium specimens was treated with four different UV light sources.

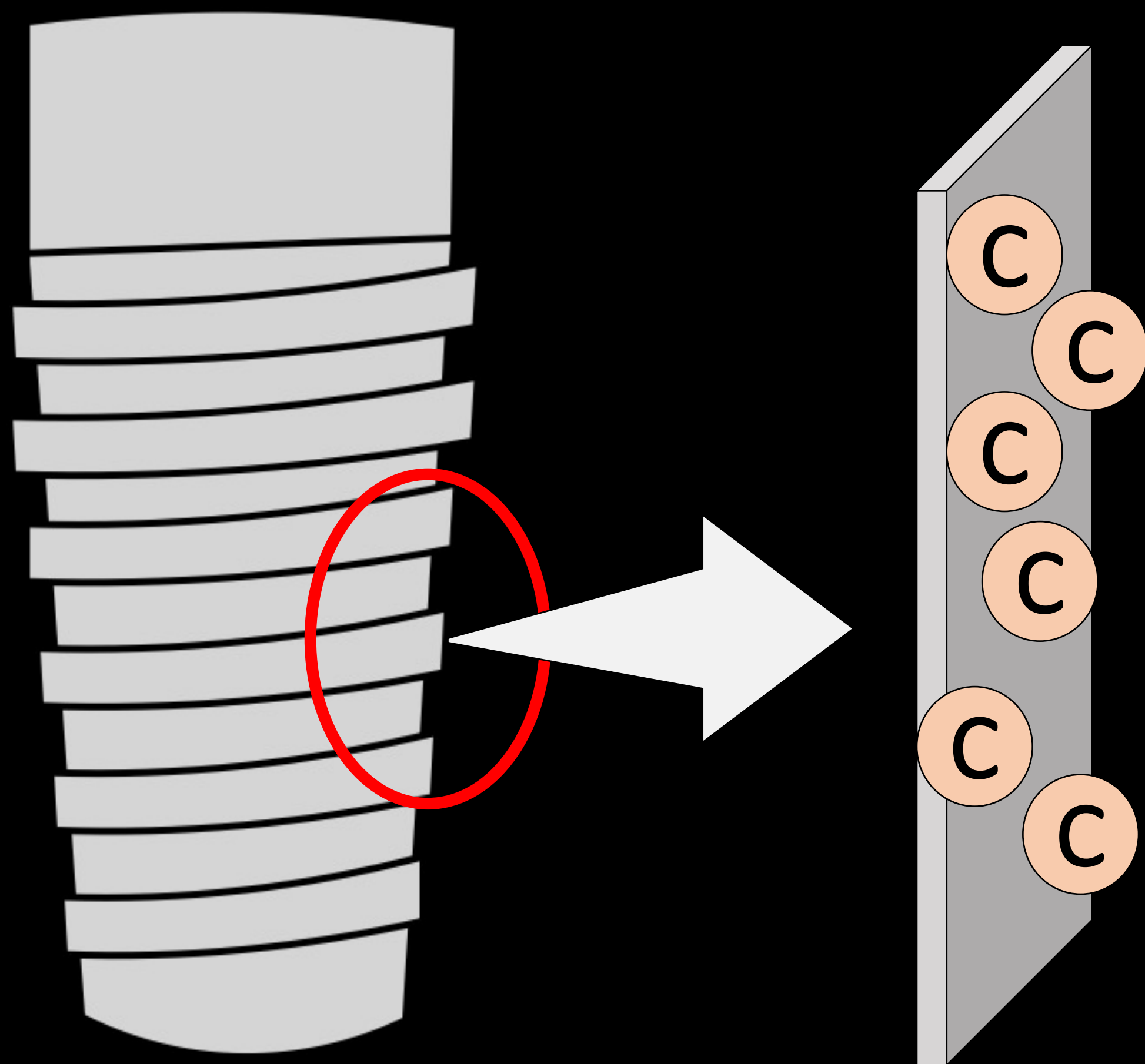
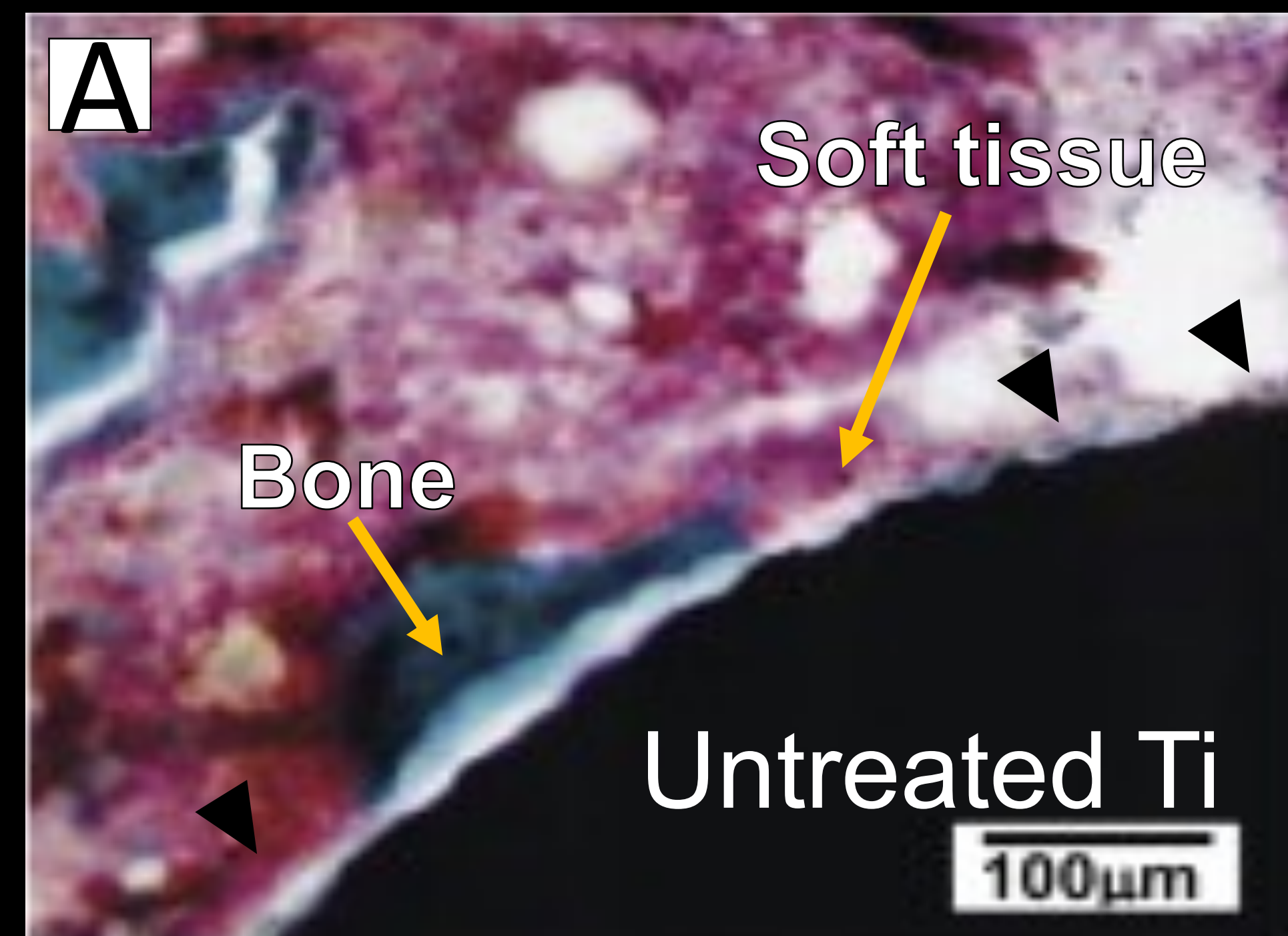


Fig. 1: Nearly 60% of the implant surface is contaminated with organic molecules



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Fig. 2: UV-treated implant prevents soft tissue from intervening between the bone and implants , leading to direct bone deposition onto the implant surface. In contrast, the bone around the untreated control involves soft tissue that migrates into between the bone and implant surface, interfering with the establishment of direct bone–implant contact.

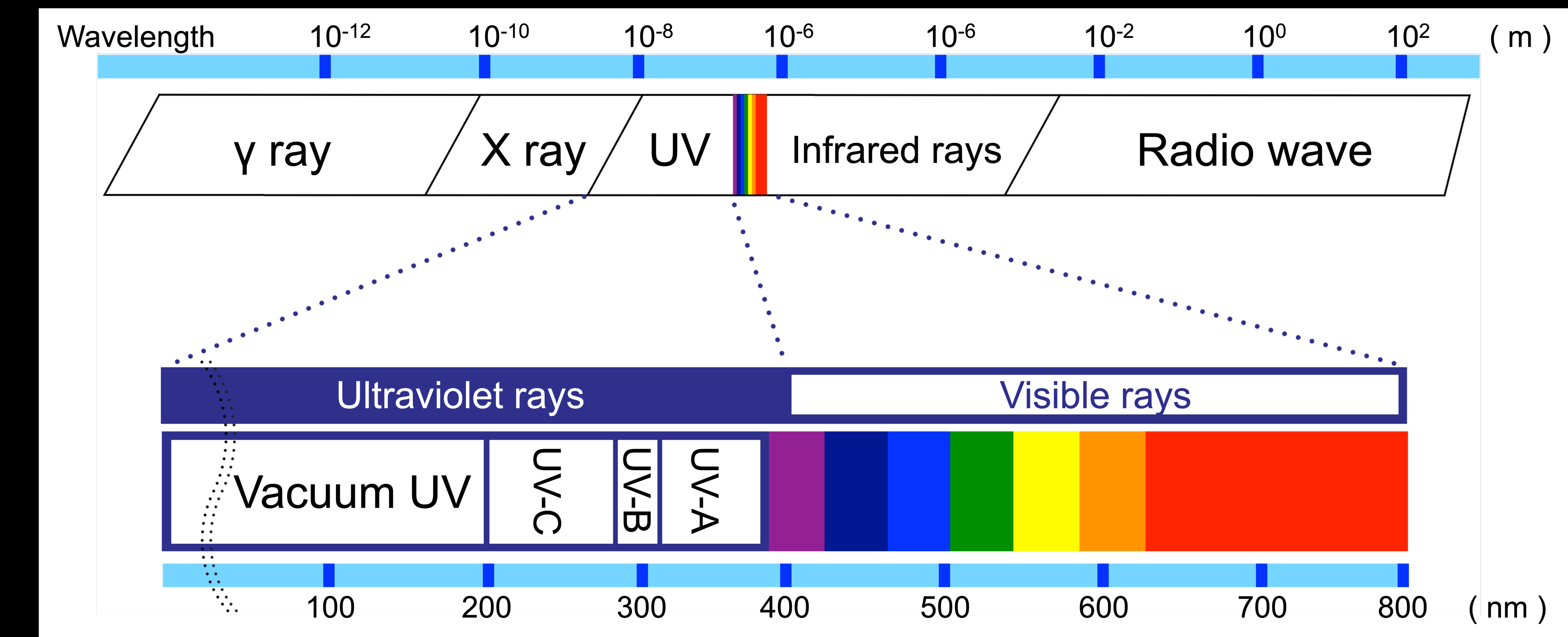
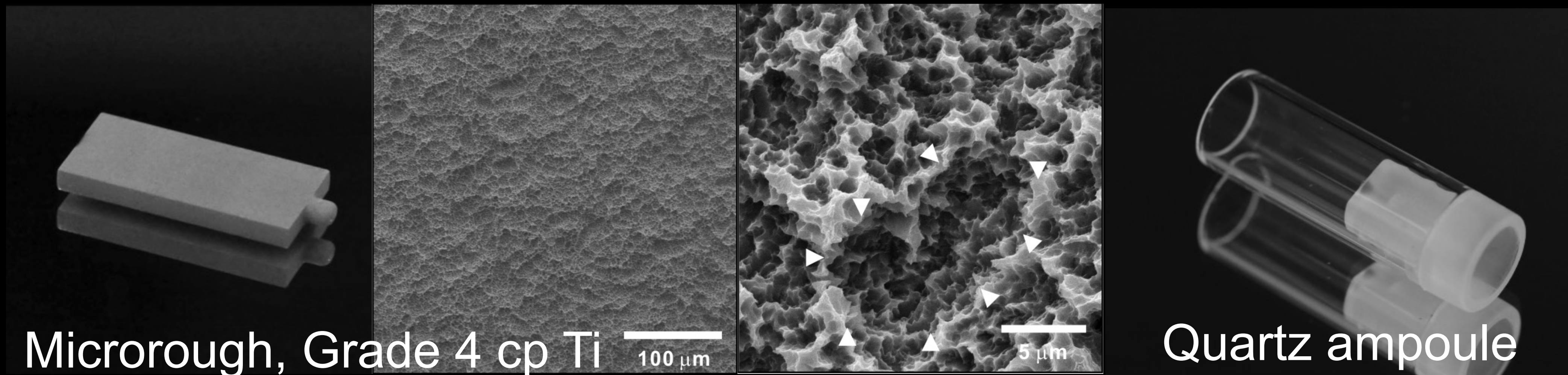


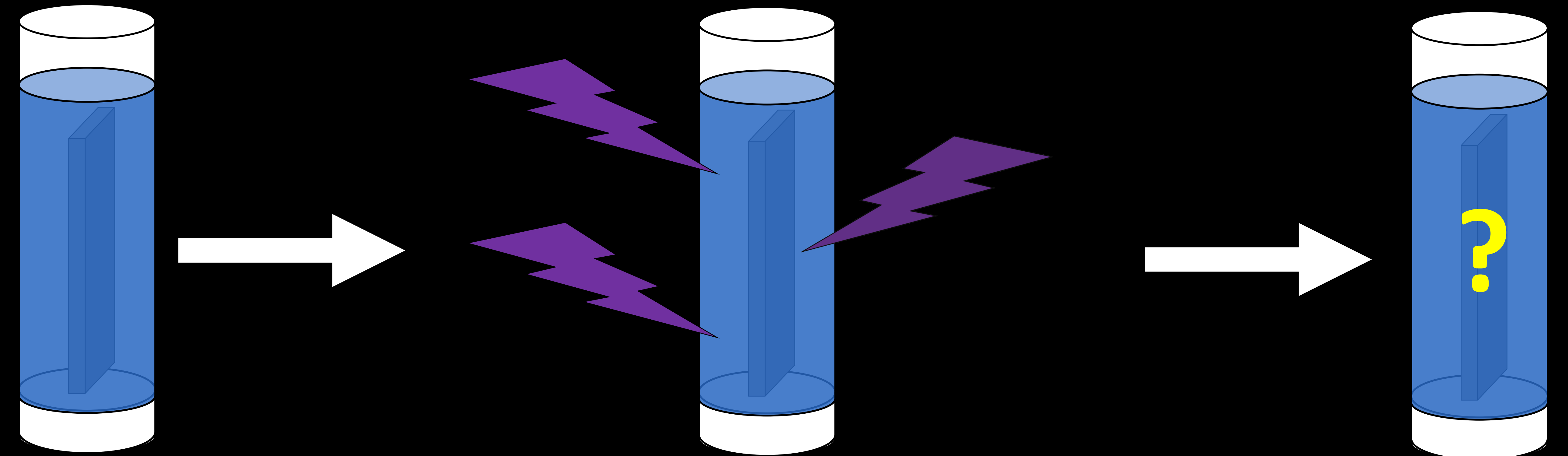
Fig. 3: Ultraviolet Spectrum

Materials



Methods

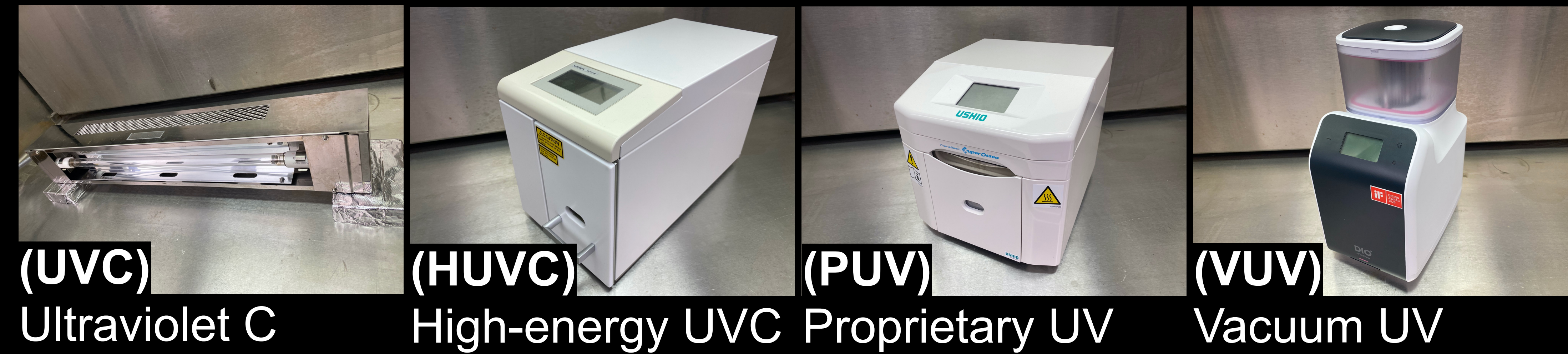
Experiment : Time dependence of VUV in organic decomposition test



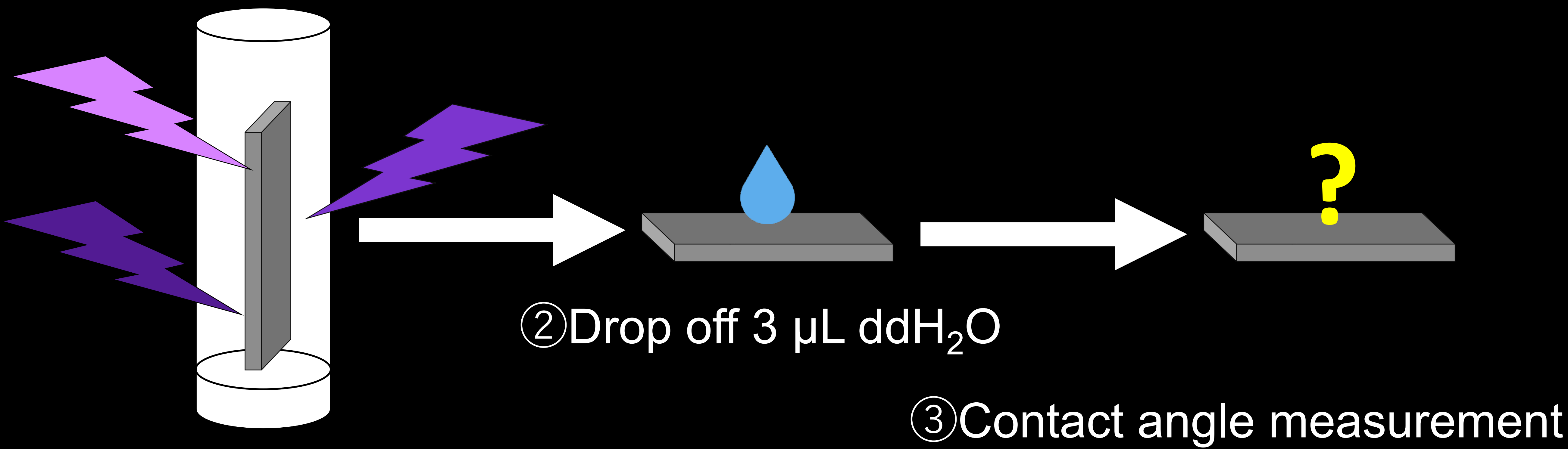
① Insert Ti plate and methylene blue solution

② VUV treated 20~100 sec.

③ Measure absorbance

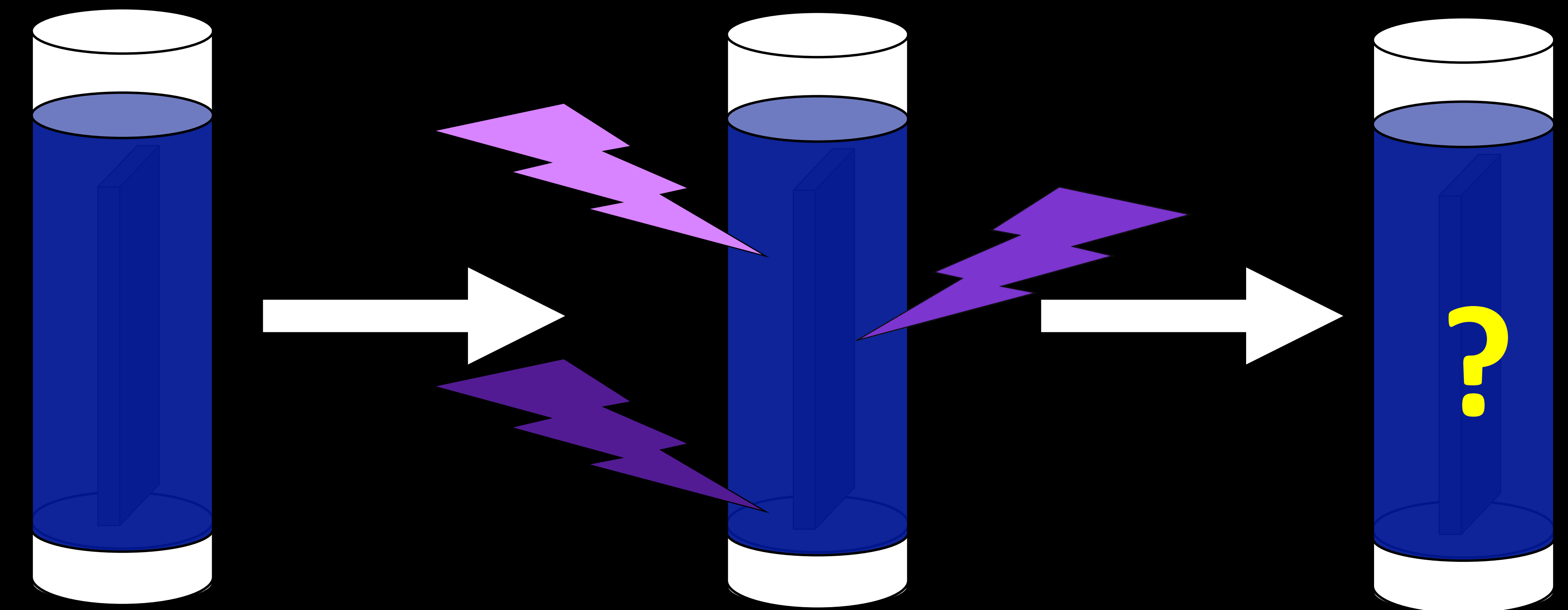


Experiment : Hydrophilicity test



① Insert Ti plate and UV treatment for 60 sec
(Four different UV light sources)
UVC, HUV, PUV, VUV

Experiment : Organic decomposition test and Load test by UV light



① Insert Ti plate and methylene blue solution

② UV treated 60 sec
(Four different UV light sources)
UVC, HUV, PUV, VUV

③ Measure absorbance

Results

Experiment :Time dependence of VUV in organic decomposition test

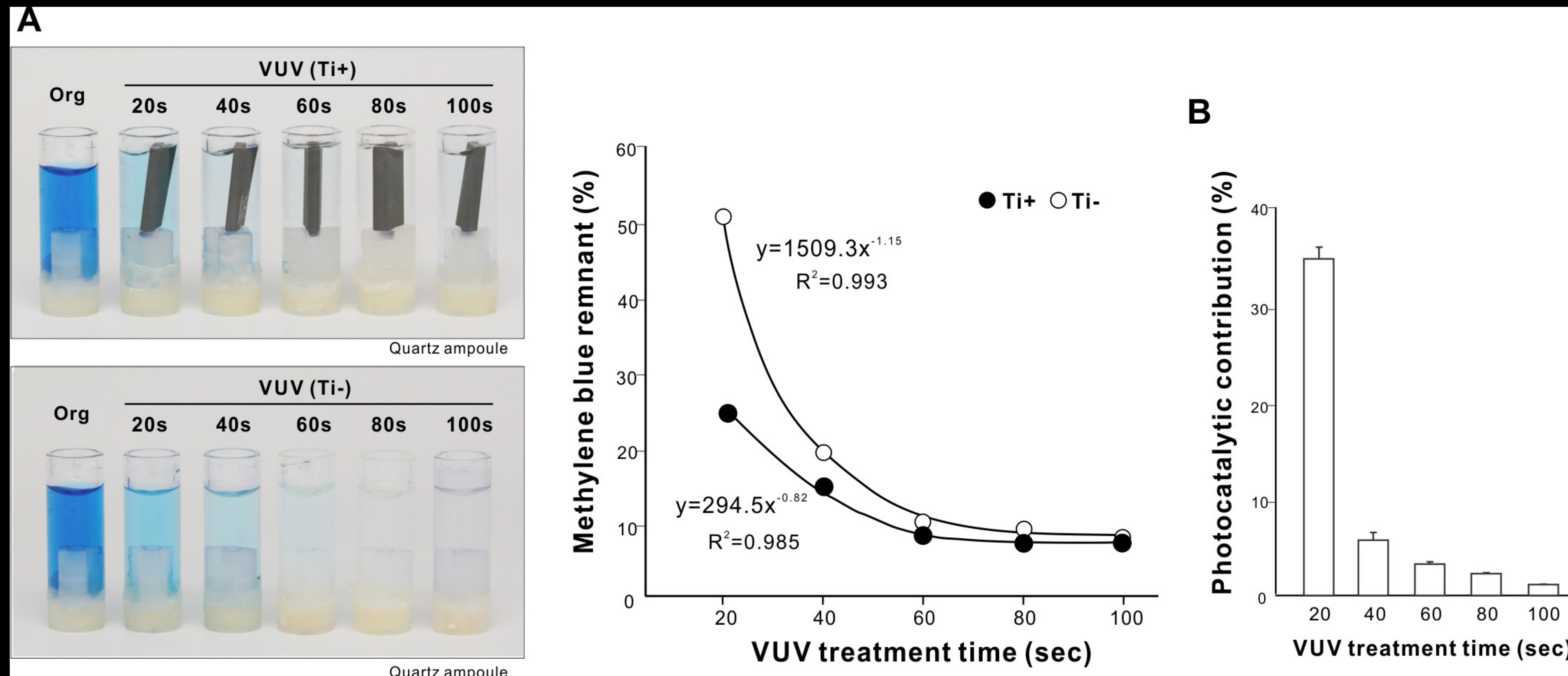


Fig. 4: Time dependence and optimization of organic degradation by VUV

Experiment : Hydrophilicity test

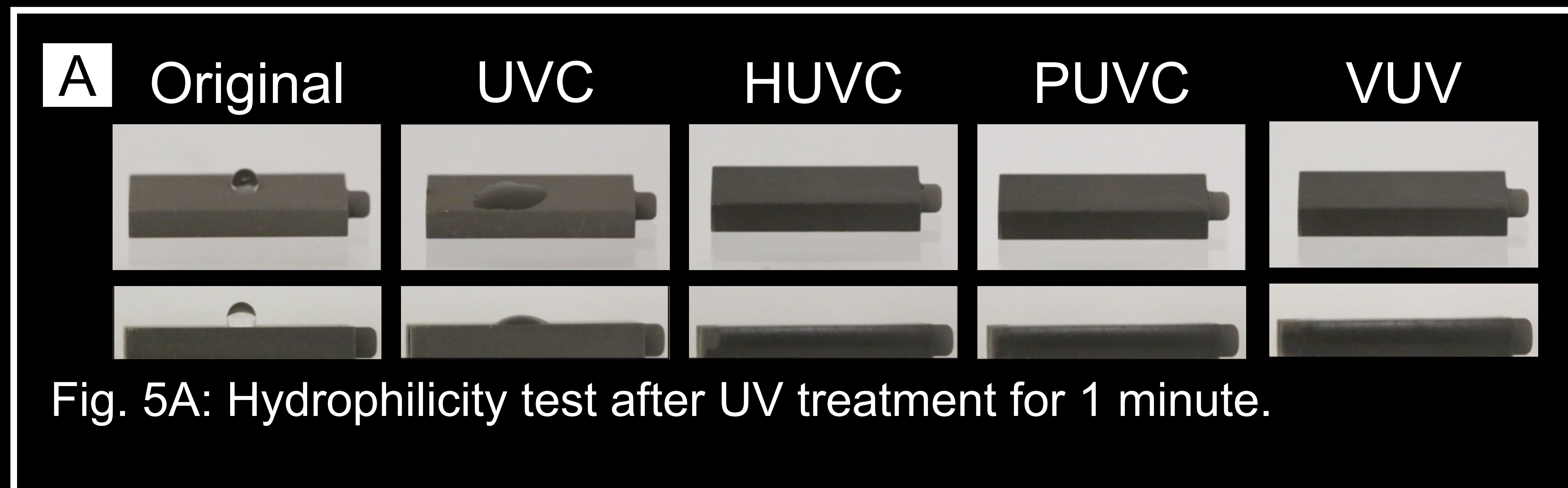


Fig. 5A: Hydrophilicity test after UV treatment for 1 minute.

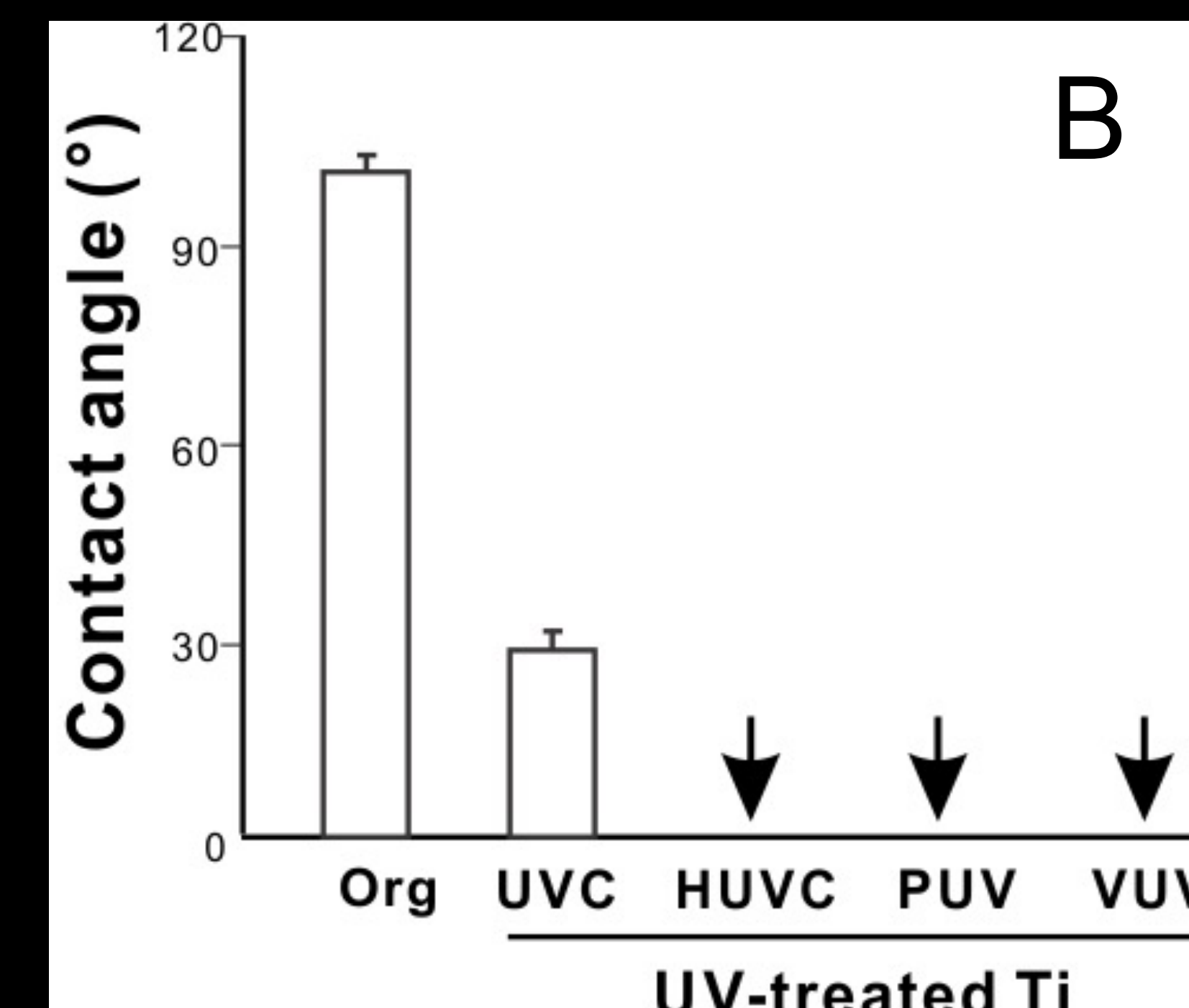


Fig. 5B: UV treated contact angle.

- The amount of remnant methylene blue significantly decreased with the increase in treatment time up to 60 s to then plateau at about 10%.
- VUV treatment without a titanium specimen showed a similar dose dependency, but with a lower efficacy of decomposition.
- The maximum effect of VUV on organic decomposition was achieved in 1 minute.

- Original titanium surfaces were hydrophobic, with a contact angle $>90^\circ$.
- All UV treatments converted the surfaces to hydrophilic (contact angle $<30^\circ$).
- The contact angle for all HUVC, PUV, and VUV treatments was 0° , and the contact angle for UVC was about 30% (Fig. 5B).

Results

Experiment : Organic decomposition test by different UV light sources

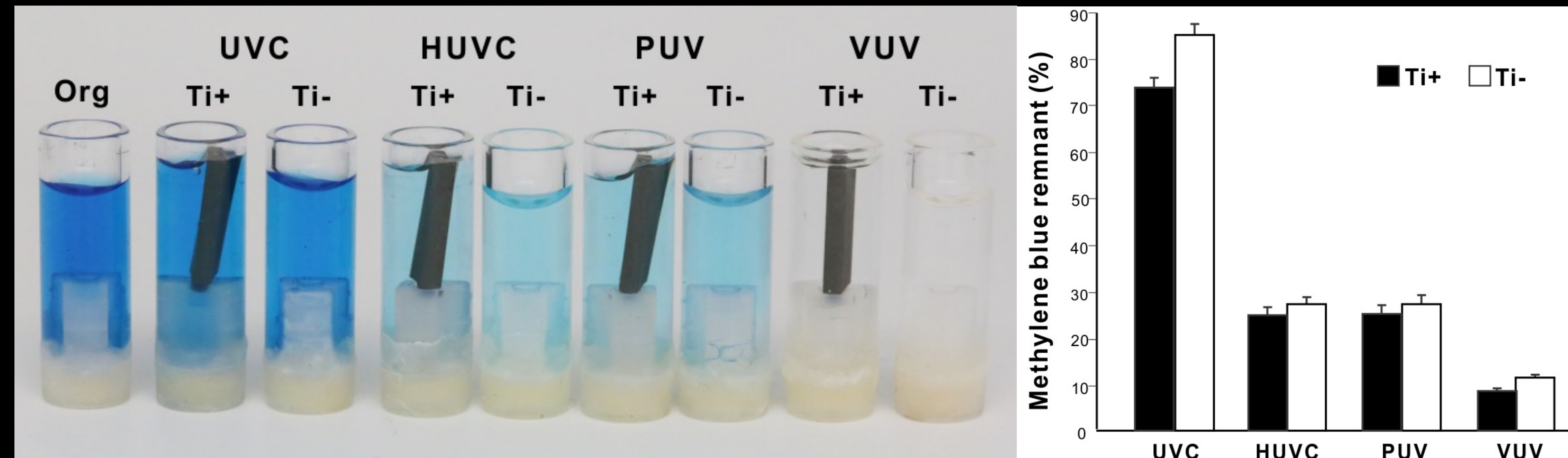


Fig. 6: Different UV sources to decompose organic molecules.

Experiment : Load testing of UV-mediated organic decomposition

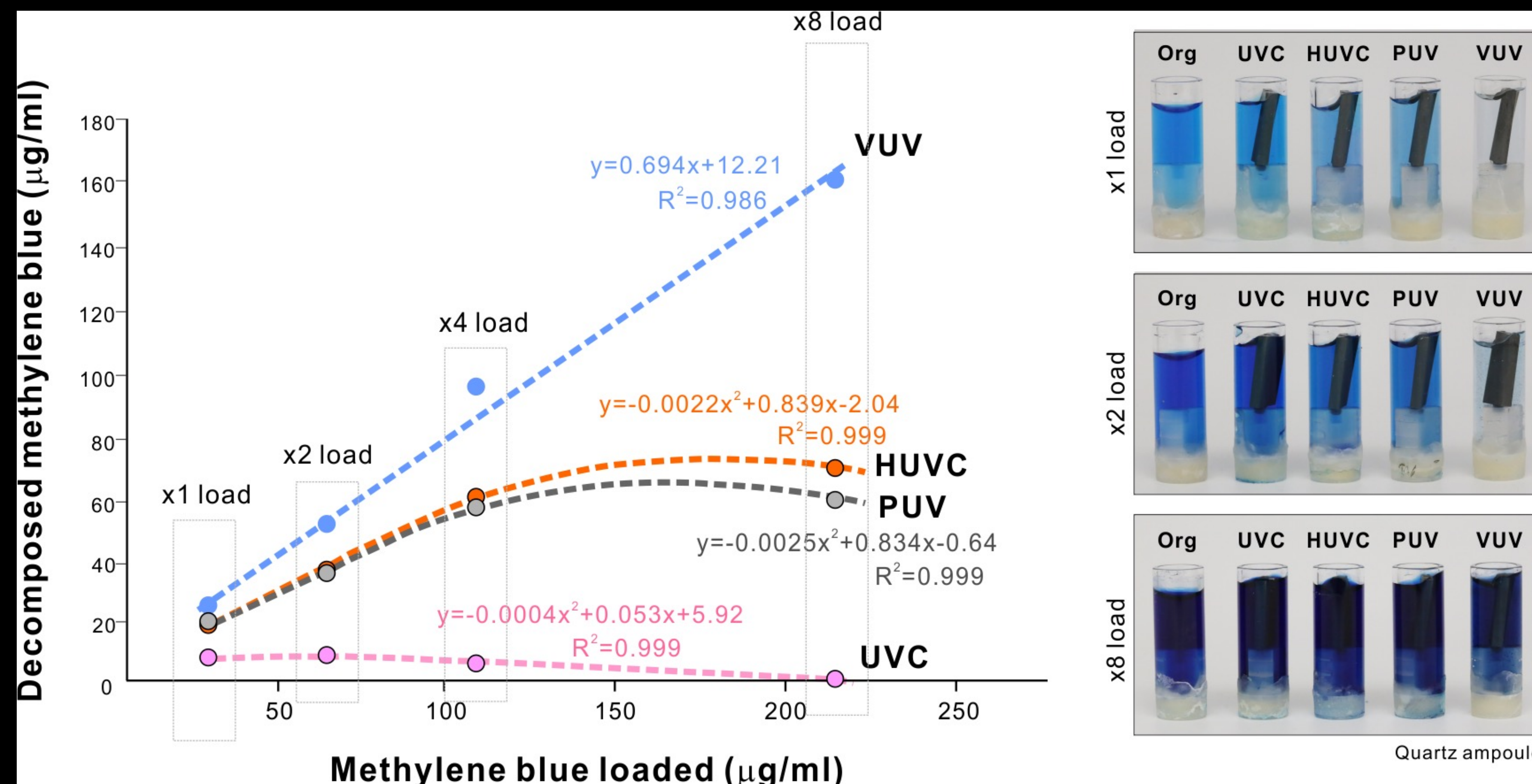
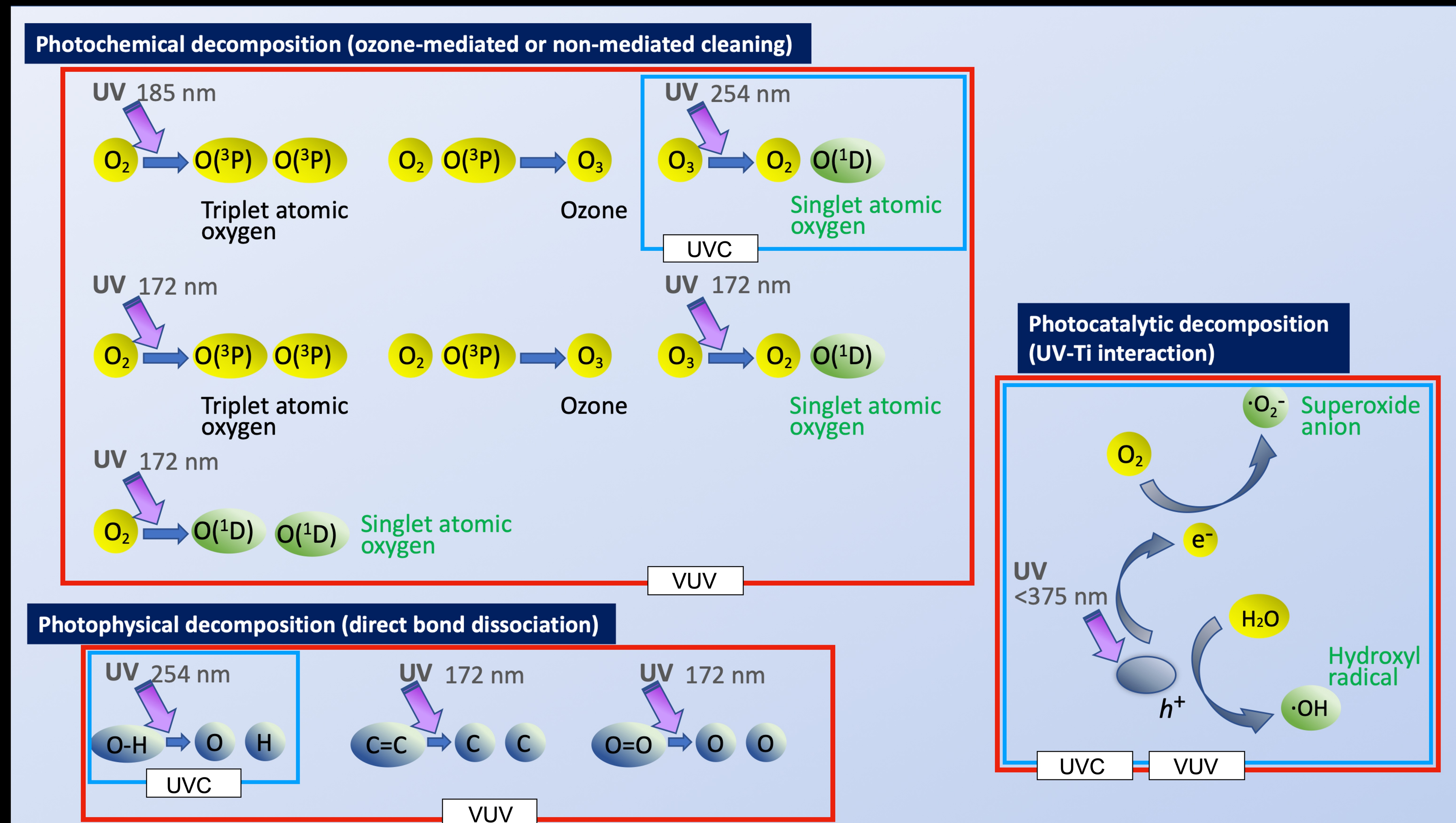


Fig. 7: Load tested different UV sources.

- All UV light sources significantly decomposed methylene blue.
- The amount of remaining methylene blue varied considerably, with UVC the highest and VUV the lowest (Fig. 6) .
- UV treatment with a titanium specimen decomposed more methylene blue than without a titanium specimen for all light sources.
- With a titanium specimen, one minute of VUV treatment decomposed over 90% of methylene blue, versus ~25% for UVC and ~75% for HUVC and PUV.

- UVC treatment did not increase the amount of decomposed methylene blue, rather declining it to near zero as the methylene blue concentration increased (Fig. 7).
- HUVC and PUV treatment showed a load-dependent increase up to x4 load, followed by a plateau or decline.
- Regression analysis fit a polynomial equation for UVC, HUVC, and PUV treatments, with very high coefficients of correlation.
- In contrast, methylene blue decomposition linearly increased with increasing VUV treatment load, with greater concentrations of methylene blue resulting in greater removal.

Discussion



Note that 172 nm VUV light has both photochemical and photophysical advantages, enabling faster and more efficient decomposition.

Fig. 8: Three mechanisms of UV-mediated organic decomposition.

Conclusions

- VUV achieved maximum organic decomposition in one minute, considerably faster than existing protocols.
- This optimization provides the empirical evidence on which to further refine the UV photofunctionalization protocol for bone integration.