Supplementary Information

Fluorescent Nanodiamond Scintillators for Beam Diagnostics of EUV and Soft X-Ray in Photolithographic Applications

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Table S1. Optical properties of bulk diamonds and nanodiamonds with NV centers as EUV/SXR scintillators

Property (unit)	**Values (notes)**	**Refs.**
Refractive index	1.00 (at 1.55 nm or 800 eV) 0.96 (at 13.5 nm or 91.8 eV) 2.41 (at 620 nm or 2.00 eV)	S1
Absorption coefficient (cm^{-1})	1.7×10^4 (at 1.55 nm or 800 eV) 9.2×10^4 (at 13.5 nm or 91.8 eV)	S1
Emission wavelength range (nm)	550 – 800	S2 – S4
Emission maximum (nm)	620	S2 – S4
Emission lifetime (ns)	17 – 20 (NV^0 in bulk diamond) 28 (NV^0 in nanodiamond)	S5 – S8 S9

References

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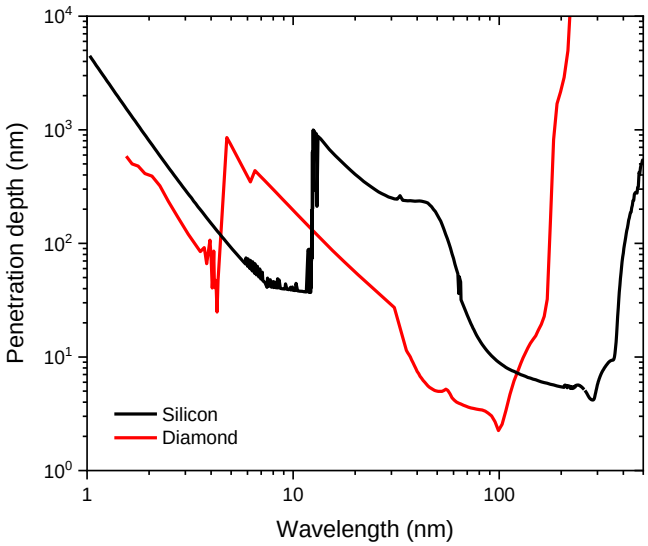

Figure S1. Penetration depths of EUV/SXR radiations in diamond and silicon.[S10,S11] The abrupt changes in the spectra result from the K-edge absorption at 284 eV (4.37 nm) of C atoms in diamond and the L2- and L3-edge absorptions at 99.2 eV (12.5 nm) of Si atoms in silicon.

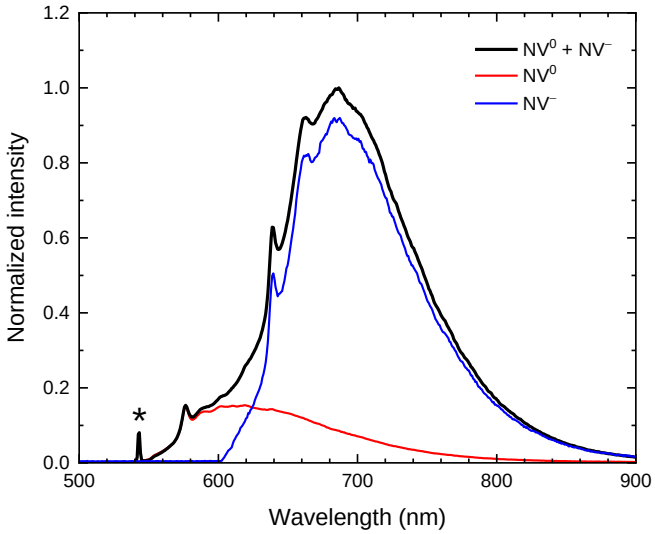

Figure S2. Normalized photoluminescence spectrum of an FND film excited with a continuous-wave 532-nm laser and their NV^0 and NV^- components after properly scaling their spectra. The asterisk denotes the unfiltered scattered laser light at 532 nm.[S8]

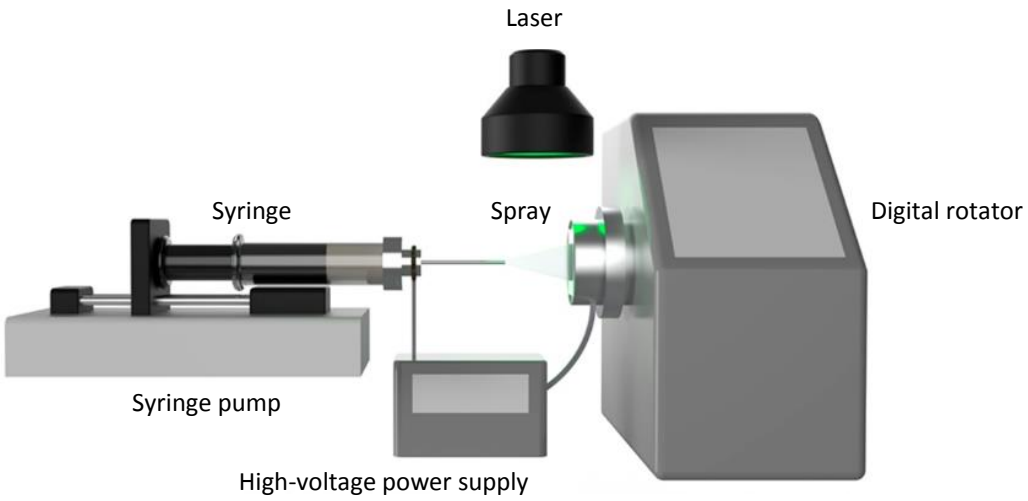

Figure S3. Schematic diagram of the experimental setup for electrospray deposition of an FND film on an electrically conductive plate. The wavelength of the laser is 532 nm.

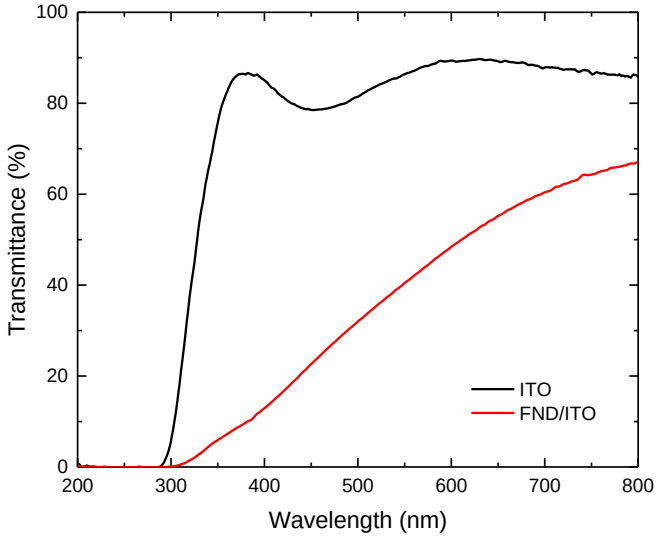

Figure S4. Typical transmission spectra of ITO/glass and FND-coated ITO/glass substrates. The spectra were acquired with a UV-Vis spectrophotometer (U-3310, Hitachi).

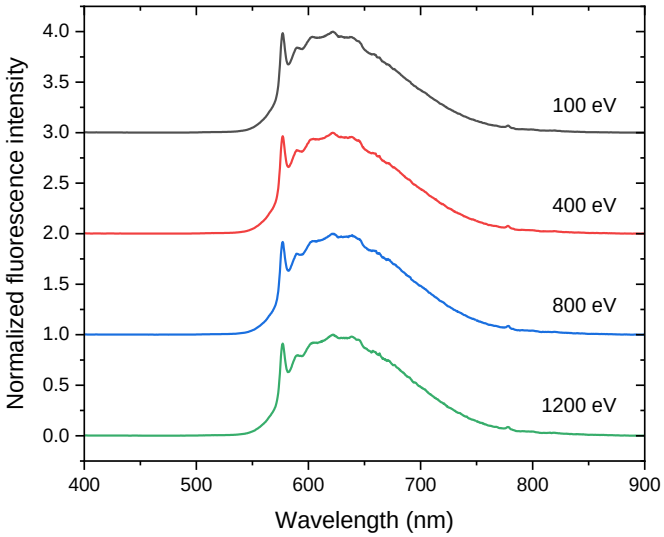

Figure S5. Normalized fluorescence spectra of FNDs, excited with EUV/SXR radiations of 100, 400, 800, and 1200 eV in energy. The spectra are shifted vertically for clarity. (Data taken from Ref. S3)

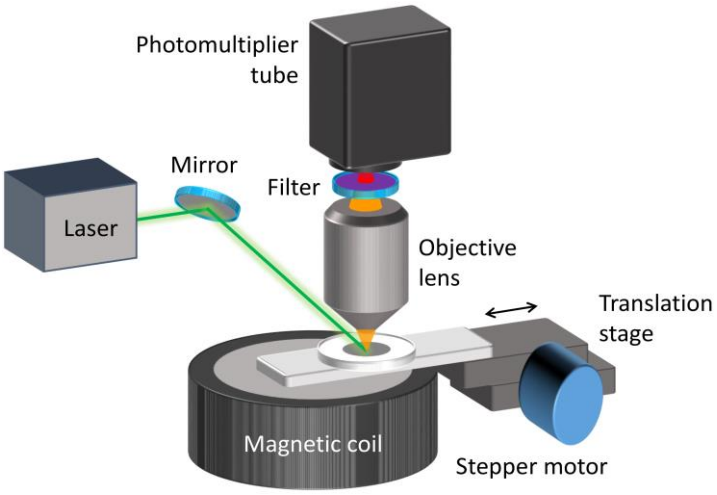

Figure S6. Schematic diagram of the experimental setup used to measure the radial dependence of the FND film thickness by magnetically modulated fluorescence. The sample irradiated by the laser beam is mounted on a motorized translation stage, allowing the fluorescence intensity line profile across the FND film to be obtained. The laser (532 nm in wavelength) has a beam diameter of ~0.7 mm and a power of 10 mW.[S12]

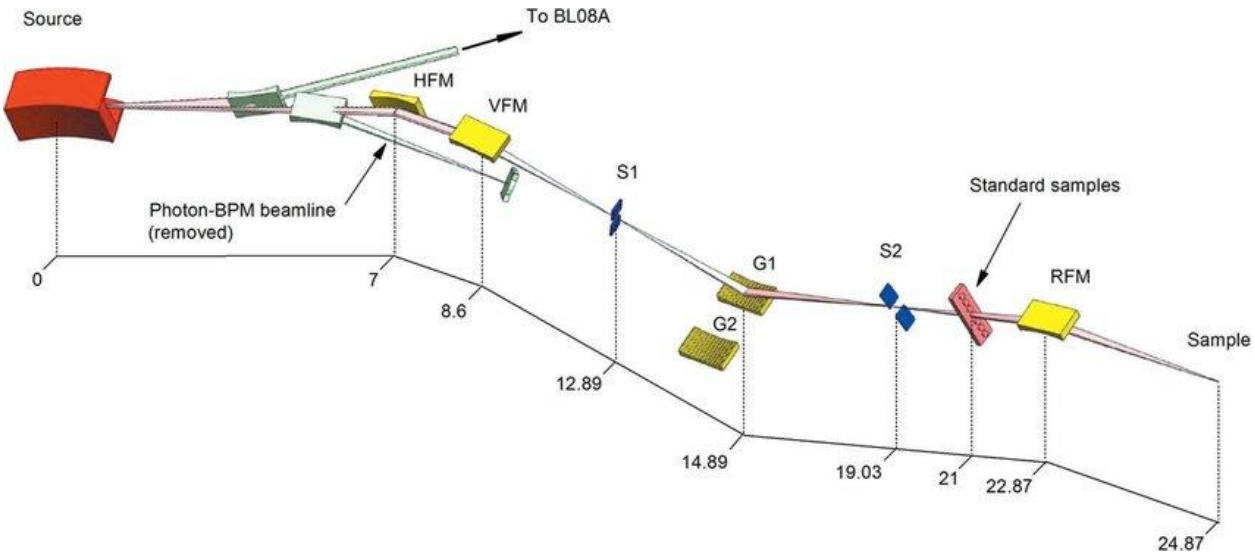

Figure S7. Optical layout of the BL08B beamline at NSRRC. Abbreviations are HFM: horizontal focusing mirror, VFM: vertical focusing mirror, S: slit, G: grating, RFM: refocusing mirror. The beamline has a bending magnet source. The numbers given underneath the components are distances in the units of meters. (Reproduced from Ref. S13 with permission from the International Union of Crystallography and Wiley)

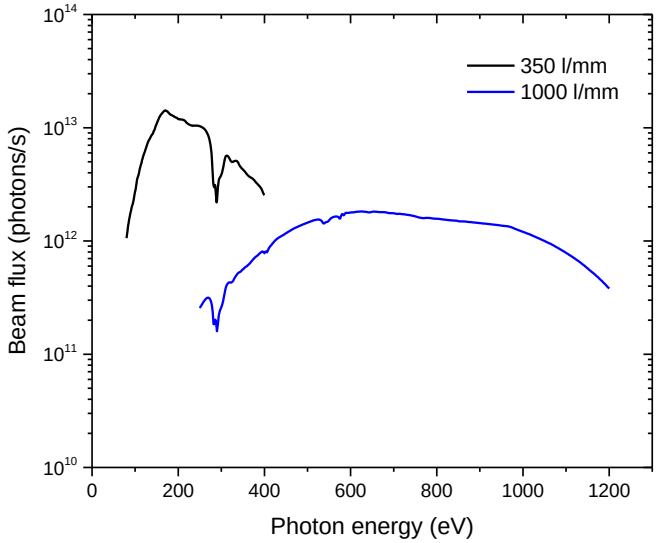

Figure S8. Photon energy spectra of the BL08B beamline at NSRRC. Two gratings, each having a ruling density of 350 and 1000 lines/mm, are used to disperse the radiations.

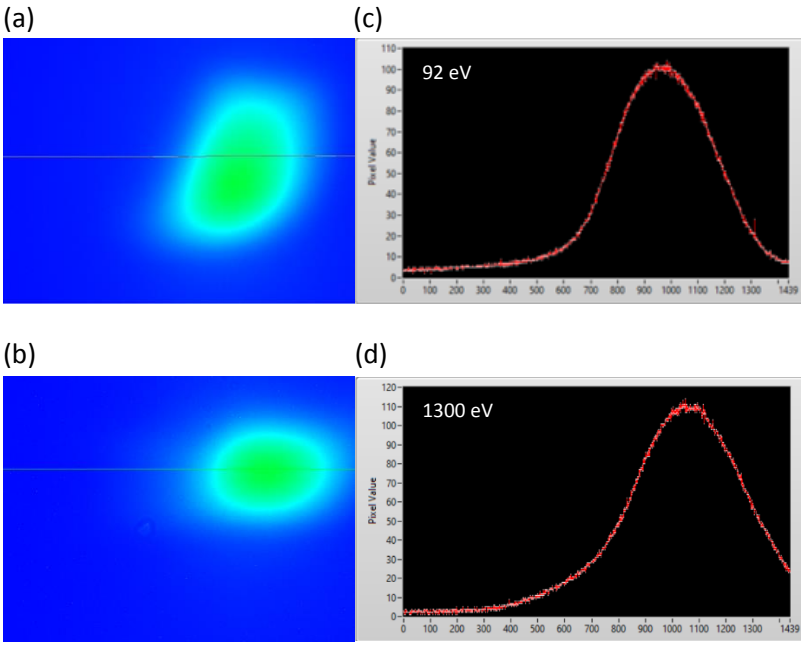

Figure S9. (a,b) Images and (c,d) intensity profiles of synchrotron radiations at 13.5 nm (a,c) and 0.95 nm (b,d), obtained with a lens-coupled DEUVI. The beam flux was 7.7×10^{11} photons/s (and 4.5×10^{10} photons/s), and the exposure time used to acquire the image in (a) (and b) was 0.5 s (and 2 s) with a gain of 1 dB. The pixel size of the imaging sensor on the CMOS camera was 3.45 μm.

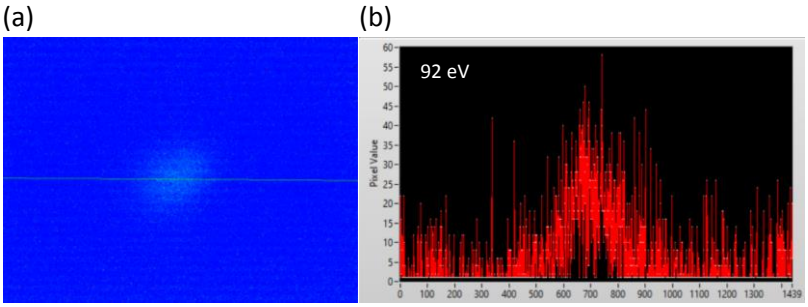

Figure S10. (a) Image and (b) intensity profile of 13.5 nm radiation, obtained with a fiber-coupled DEUVI system at its detection limit. The beam flux was 3.9×10^8 photons/s, and the camera was operated at an exposure time of 1 s and a gain of 30 dB. The sensing area of the CMOS camera was 4.97 mm × 3.73 mm.