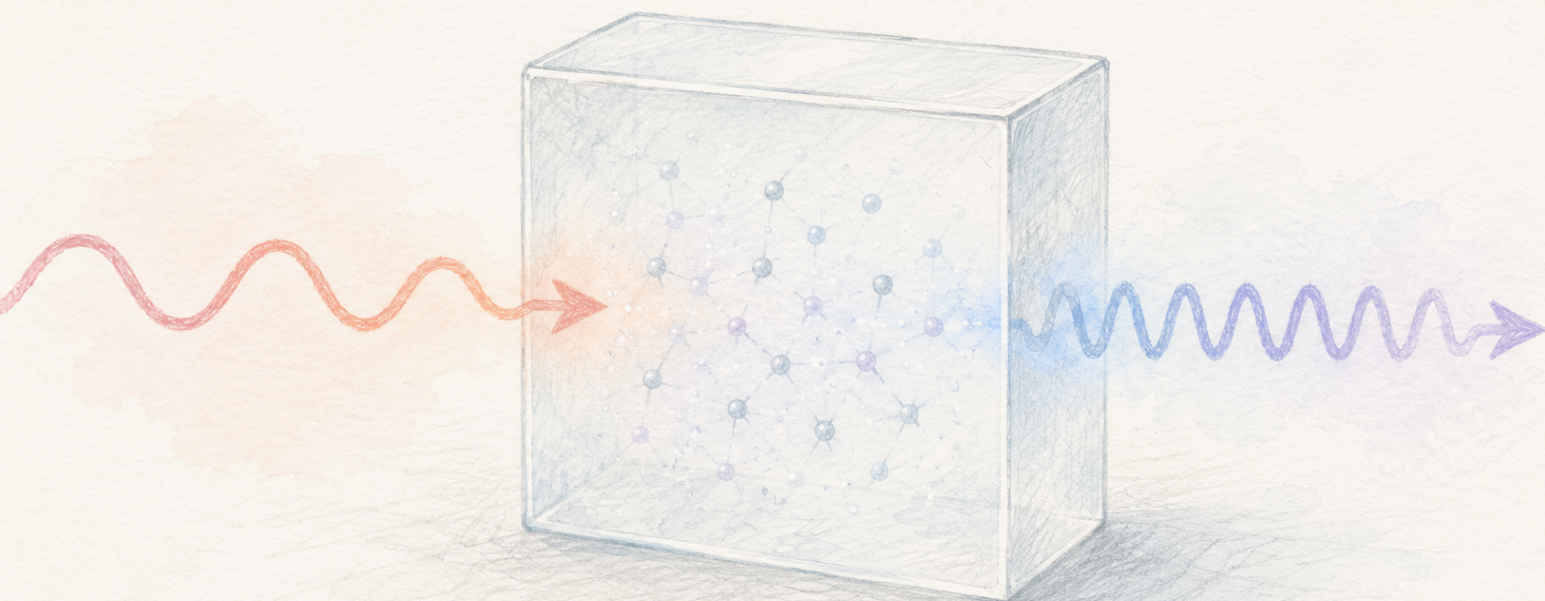




The CLEAN PAPER

WHAT THE PAPER SAYS · WHAT IT DOESN'T · WHY IT MATTERS

Solid material tokko visible blue light gara UVtti
sunlight-level intensity irratti jijjiira — garuu
solar-energy machine miti

Qorattoonni DHI-based organic crystals alkyl side chains π -electron system eegan, triplet energy socho'uu immoo hin dhorkine, engineer godhan. Best iBu-DHI/Ir(ppy)₃ solid film visible-to-UV triplet-annihilation upconversion 1.9% absolute quantum yield fi 1.2 mW cm⁻² threshold, solar intensity naannoo 445 nm waliin wal-dhiyaatu, argate. Kun solid-state photon upconversion'f materials advance dhugaa dha. Working solar device miti, 'free UV' miti, visible sunlight useful UV chemistry scale guddaan oofuu danda'a jechuun proof miti.

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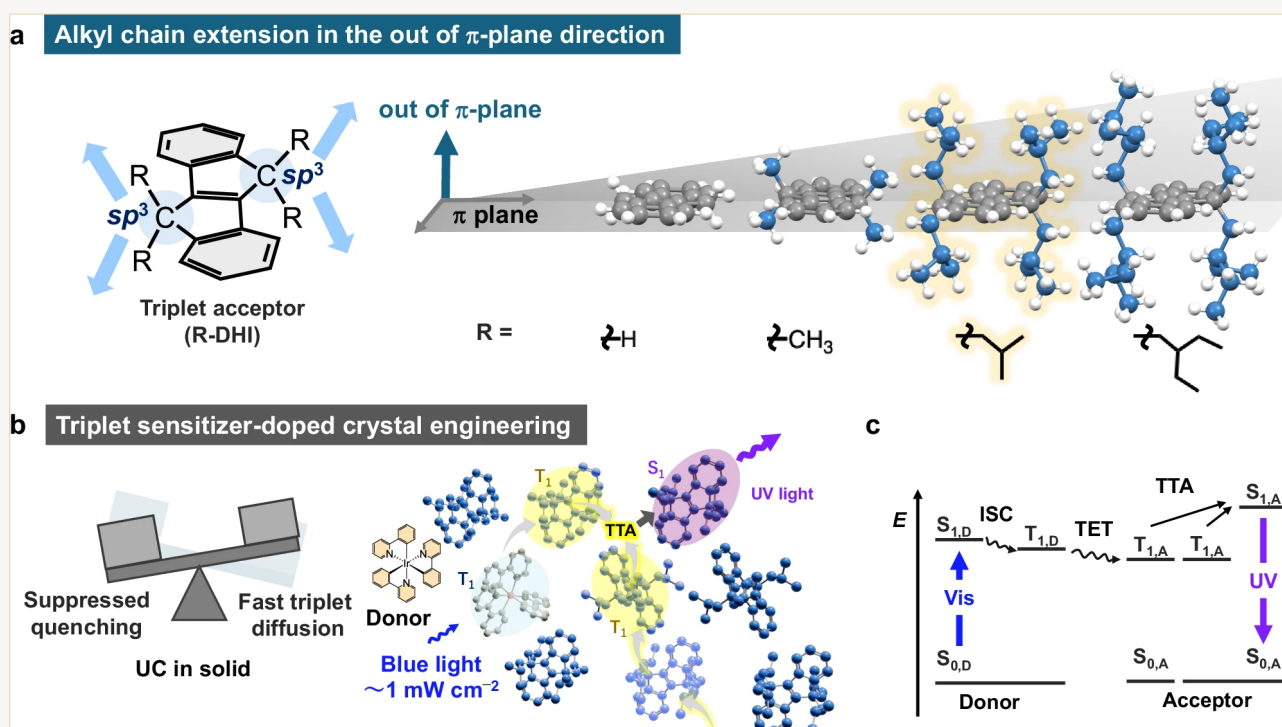
Paper: *Sterically protected π -electron systems for efficient solid-state photon upconversion*, Naoyuki Harada, Hayato Shoyama, Nutnicha Boonmong, Kiichi Mizukami, Yuya Watanabe, Pei Zhao, Masahiro Ehara, Yoichi Sasaki, and Nobuo Kimizuka, Nature Communications 17, 5134 (2026) · DOI: 10.1038/s41467-026-73898-0

Mala sunlight-level irratti hojjetu — solar-energy machine miti

Ifa aduu lafa ga'u keessaa harki guddaan mul'ataa fi infrared dha. Ultraviolet (UV) kutaa xiqqaa qofa, garuu UV photons chemically humna guddaa qabu: reactions mul'ataa photons anniisaa gadi-aanaa qaban hin dandeenye oofuu danda'u. Kanaaf **photon upconversion** yaada nama hawwatu dha. Maateriyaalii tokko mul'ataa photons anniisaa gadi-aanaa lama fudhatee UV photon anniisaa ol-aanaa tokko deebisuu yoo danda'e, mul'ataa sunlight chemistry yeroo baay'ee UV barbaadu keessatti fayyadamuu dandeenya.

Barruu kun gosa ulfaataa rakkoo kana irratti: mul'ataa-to-UV upconversion **jajjabaa** keessatti, **sunlight-level intensity** irratti, molekiyuulota furmaata keessatti freely diffayyadaman irratti hirkachuu malee. Kun barbaachisaa dha, sababni furmaata sirnoota efficient ta'uu danda'anis devices'f awkward dha: solvent evaporate gochuu, leak gochuu yookaan long-term fayyadama daangessuu danda'a. Solids hojiirra oolu caalaa, garuu excited haalawwan upconversion barbaachisu yeroo baay'ee balleessu.

Kanaaf bu'aa dhugaa “sunlight irraa UV bilisaa” miti. Materials-chemistry keessatti contradiction tokkoof furmaata dha: jajjabaa keessatti molekiyuulota tiripileetii anniisaa akka socho'uuf walitti dhiyaachuu qabu, garuu baay'ee walitti dhiyaatanii wal-dadhabsiisuu hin qaban.



Qophii logic barruu kanaa: acceptor molekiyuulota alkyl side chains plane π keessaa ol-bahaniin jijjiiraman, kanaan kiristaala keessatti packing isaanii jijjiirama. Kaayyoon jajjabaa keessatti tiripileetii anniisaa saffisaan socho'uu danda'u, garuu quenching irraa dhabamuu xiqqaa qabu uumu. Sensitizer jalqaba mul'ataa blue ifa absorbee tiripileetii anniisaa acceptors'tti dabarsa; acceptor triplets lama wal-argan yeroo ta'u triplet-triplet annihilation UV photon anniisaa ol-aanaa uumu danda'a. Kun molekiyuulii qophii, solid-state tradeoff fi energy-transfer karaa cuunfa; device raawwii kallattii safartuu miti.

Barreessitoonni maal godhan

Adeemsa hojii'n **tiripileetii–tiripileetii annihilation photon upconversion** (TTA-UC) dha. Salphifnee:

1. donor molekiyuulii mul'ataa ifa absorbee long-lived tiripileetii excited haala uuma;
2. tiripileetii anniisaa sun acceptor moleculetti transfer ta'a;
3. excited acceptors lama wal-argu;
4. anniisaa isaanii walitti ida'amee singlet haala anniisaa ol-aanaa tokko uuma;
5. acceptor photon anniisaa ol-aanaa — asitti ultraviolet — baasa.

Liquids keessatti tarkaanfii 3 molekiyuulii diffusion'n gargaara. Molekiyuulota socho'anii walitti bu'u. Jajjabaa kiristaala keessatti hin socho'an. Anniisaa packed maateriyaalii keessa socho'uu qaba; packing immoo sirriitti qindaa'uu qaba.

Barreessitoonni family molekiyuulota **dihydroindeno[2,1-a]indene** (DHI) irratti hundaa'e fayyadaman. Qophii move isaanii conceptual ta'een salphaa: alkyl chains molekiyuulii π -elektiroonii plane isaa ol fi gadiitti maxxansiisuu. Side chains kun spacers/bumpers fakkaatu. Fluorescent π -sirna baay'ee walitti ciminaan walitti kuusuu irraa ittisu, quenching xiqqeessa; yeroo wal-fakkaatutti orbiitii contact tiripileetii anniisaa akka socho'uuf barbaachisu eega.

Derivatives hedduu qorarii **iBu-DHI** — isobutyl-substituted gosa — balance gaarii ta'uu argan. Tiripileetii donor **Ir(ppy)₃** waliin walitti makanii crystalline jajjabaa films spin-coating yookaan drop-casting'n uuman; fluorescence, tiripileetii lifetime, tiripileetii diffusion amala, upconversion quantum yield, oksijiinii tolerance fi daangaa excitation intensity safaran.

Maal argatan

Side chains excited haalawwan eegan. Plain DHI dilute furmaata keessatti baay'ee gaariitti fluoresce godha, kiristaala keessatti garuu hamaa: fluorescence quantum yield 96% furmaata irraa gara 10% crystalitti gadi bu'a. iBu-DHI keessatti kiristaala'n ammallee cimaa fluoresce godhe — grinding dura naannoo 69%, grinding booda 83%, furmaata gatii waliin wal-fakkaata. Kun mala keessaa walakkaa jalqabaa: jajjabaa singlet excited haala salphaatti hin balleessu.

Jajjabaa film gaariin mul'ataa ifa gara UVtti gadi-aanaa intensity irratti upconvert godhe. Spin-coated iBu-DHI/Ir(ppy)₃ film keessatti, self-absorption correction booda absolute upconversion quantum yield **1.9%**, daangaa excitation intensity **1.2 mW cm⁻²** at 445 nm gabaasan. Isaan solar irradiance wavelength sana naannoo, **1.4 mW cm⁻²** for 445 ± 5 nm, waliin wal bira qabu. Afaan salphaan: maateriyaalii'n intensity idilee sunlight daangaa keessatti hojjetu, leezerii baay'ee humna qabu qofa irratti miti.

Solid-state raawwii compromise irraa dhufe; bulk dabaluu qofa irraa miti. Molekiyuulota wal irraa fageessuun quenching hir'isuu danda'a, garuu separation baay'ee guddaan tiripileetii anniisaa migration suuta godha. Bulky 2-EtBu-DHI derivative tiripileetii lifetimes dheeraa qaba, garuu upconversion daangaa amala hamaa. iBu-DHI kiristaala faayidaa qabu middletti dhiyaata: quenching ittisuuf steric protection gahaa, tiripileetii transfer fi tiripileetii–tiripileetii annihilation'f contact molekiyuulii gahaa.

Maateriyaalii'n furmaata sirna qofa freeze godhame miti. barruun crystalline packing, homogeneous donor distribution fi dense molekiyuulii assembly hundi barbaachisaa akka ta'an falma. SEM-EDX kaartawwan films barbaachisoo keessatti micrometer-scale donor segregation hin agarsiifne; donor phosphorescence quenching tiripileetii anniisaa transfer efficient ta'uu agarsiise. Supplementary maateriyaalii tiyoorii tilmaamota tiripileetii anniisaa transfer fi annihilation yeroowwan molekiyuulii pairs kiristaalota keessatti illee qaba.

Oxygen-tolerant emission agarsiise. Oksijiinii tiripileetii haalawwan yeroo baay'ee quench godha, TTA-UC'f nuisance guddaa. Dense jajjabaa films air keessatti upconversion agarsiisuu itti fufan, jalqabaa oxygen-consuming turn-on period booda. Hojiirra oolu ta'uu danda'a, garuu long-term outdoor device stability ragaa miti.

Kun maal jechuu akka malu

Dubbisuu defend gochuun danda'amu: kun materials-design bu'aa qulqulluu dha. Barreessitoonni packing organic π -elektiroonii sirna qindeesuun jajjabaa tokko mul'ataa-to-UV upconversion kan furmaata keessatti salphaa ta'e akka hojjetu godhan. Advance photon upconversion jiraachuu isaa miti; sirna solid-state kana keessatti amaloota yeroo baay'ee wal morman walitti fiduu dha: fluorescence yield ol-aanaa, tiripileetii lifetime dheeraa, fast tiripileetii diffusion, oksijiinii tolerance, fi operation solar irradiance naannoo.

Lesson bal'aan molekiyuulii kana ala illee faayidaa qabu dha. Solid-state TTA-UC keessatti gaaffin “excited haalawwan akkamitti eegna?” fi “tiripileetii anniisaa akkamitti sochoosna?” addaan miti. Molekiyuulii spacing akkamitti engineer goonee lamaan yeroo tokko dhugaa goona? iBu-DHI fakkeenya ifa ta'e principle kanaa dha.

Overreading nama hawwatu ifaadha: mul'ataa sunlight gara UVtti jijjiirame, kanaaf solar chemistry furame. barruun kana hin agarsiisu. Maateriyaalii photophysical adeemsa hojii promising fi raawwii lakkoofsota addaa qabu, to'atame films fi optical haalawwan defined keessatti, agarsiisa.

Kun maal *hin* mirkaneessu

- **Solar-energy device miti.** Guutuu device hin jiru, outdoor module hin jiru, system-level anniisaa balance hin jiru, faayidaa qabu chemical bu'aa film kanaan humna qabu hin demonstrate.
- **“Sunlight irraa UV bilisaa” miti.** Jajjabaa keessatti upconversion quantum yield **1.9%**, guutuu

conversion irraa fagoo. Maateriyaalii class kanaaf hiika qabu dha, garuu galtee photons hedduun UV hin ta'an.

- **Dhugaa fayyadama keessatti durability bal'aa hin agarsiisu.** Photostability fi oksijiinii tolerance to'atame settings keessatti qoran; ho'a, humidity, oksijiinii, mechanical stress fi broadband sun-light jalatti ji'oota/waggoota device operation waliin wal-qixa miti.
- Maateriyaalii donor-acceptor sirna addaa irratti hirkata. Isa gaarii bu'aa iBu-DHI + Ir(ppy)₃ fayyadama. Molekiyuulii variants dhihoo illee baay'ee caalaatti hamaa ta'uu barruun agarsiisa; "alkyl chains dabali, ni hojjeta" jechuun recipe waliigalaa miti.
- Hojiirra oolu concerns hunda hin balleessu. Ir(ppy)₃ iridium qaba; Supplementary yaaliiwwan keessatti metal-free TADF donors illee agarsiisu, garuu mata-duree isa gaarii haala iridium-donor sirna dha.
- Visible-to-UV upconversion photocatalysis, solar fuels, sensing yookaan sterilization'f economically/technologically faayidaa qabu ta'uu hin mirkaneessu. Kanneen danda'amaa fayyadamoota qofa, bu'aawwan barruu kanaa miti.

Ragaan hammam cimaa dha?

Central photophysical himannaa irratti ragaa cimaa dha: absorption/emission safartuuwwan, fluorescence quantum yields, tiripileetii lifetimes, excitation-intensity daangaalee, upconversion speaktra, absolute quantum-yield safartuuwwan, kiristaala caasaalee, donor-distribution sakatta'awwan, supplementary madda daataa fi tiyoorii shallaggiwwan packing adeemsa hojii proposed deeggaraa gabaasan. Nature Communications article banaa access dha; supplementary odeeffannoo fi source-data file jiru dha.

Caution ijoo scope dha. xumura cimaa: maateriyaalii lab characterization keessatti. "Solid-state film 1.9% mul'ataa-to-UV upconversion, sunlight-level blue intensity naannoo" irraa gara "faayidaa qabu solar technology"tti tarkaanfiin guddaa dha. Integration, stability, faayidaa qabu bu'aa, scalable manufacturing fi sababni upconverted UV photons karaa chemistry sochii gochuuf malleen biroo caalaa gaarii ta'an barbaachisa.

Wording subtle tokko illee jira. "Sunlight-level" intensity wavelength excitation yaalii keessatti fayyadame naannoo agarsiisa; dhugaa device keessatti guutuu solar speaktrumii efficiently operate gochuu automatically miti. Garaagarummaan kun barbaachisaa dha.

Maaliif barbaachisaa dha

Photon upconversion hamaan ibsuun salphaa: photons dadhabaa lama seenu, photon cimaa tokko ba'a. Garuu hard kutaa slogan miti. Molekiyuulota dhugaa akkamitti qindeessina akka anniisaa yeroo gahaa store ta'u, fageenya gahaa socho'u, achiis ho'a ta'ee baduu dura walitti makamuu danda'u?

Barruu kun rakkina sana molekiyuulii/maateriyaalii bifa qabaachiisa. Side chains decoration miti. Molekiyuulii architecture dha: π -sirna ol fi gadi irraa eega, quenching xiqqeessa, akkasumas tirip-

ileetii anniisaa socho'uuf path dhiisa. Kun kutaa barsiisuuf gatii qabu, sababni “caalaatti gaarii maateriyaalii” vague jedhu fiizikaalaa compromise namni yaadu danda'utti jijjiira.

Fuuldura mul'ataa-to-UV upconversion devices faayidaa qabu yoo ta'an barruu kana booda tarkaanfiiwwan hedduu barbaadu. Garuu molekiyuulii to'annoo akkanaa illee barbaadu. Bu'aa device breakthrough miti; jajjabaa tokko photophysical trick solids yeroo baay'ee balleessan akka hojjetu gochuuf demonstration cimaa dha.

Cuunfaa gabaabaa

Qorattoonni DHI-based organic molekiyuulota alkyl side chains π -elektiroonii plane ol fi gadi irraa eegan qopheessan. Isa gaarii haala keessatti iBu-DHI tiripileetii donor Ir(ppy)₃ waliin crystalline jajjabaa film uume, mul'ataa blue ifa gara ultraviolet emissionatti tiripileetii–tiripileetii annihilation'n jijjiire. Film absolute upconversion quantum yield **1.9%** fi daangaa excitation intensity **1.2 mW cm⁻²**, solar irradiance naannoo wavelength 445 nm waliin wal-dhiyaatu, ga'e. Advance dhugaan molekiyuulii packing dha: excited-state quenching xiqqeessuuf separation gahaa, tiripileetii anniisaa transfer fi diffusion'f contact gahaa. Kun solid-state mul'ataa-to-UV photon upconversion irratti maateriyaalota demonstration cimaa dha — solar-energy device miti, “free UV” miti, deployed technology ragaa miti.

Sakatta'a ifaa

barruun maal agarsiisa: iBu-DHI/Ir(ppy)₃ crystalline jajjabaa film addaa mul'ataa-to-UV TTA photon upconversion 1.9% absolute quantum yield fi 1.2 mW cm⁻² daangaa at 445 nm waliin hojjetu; fluorescence yield ol-aanaa, tiripileetii lifetime dheeraa, fast tiripileetii diffusion fi oksijiinii tolerance muuraasa qaba. Qophii'n sterically π -sirna eegu, molekiyuulii contacts faayidaa qabu eegu irratti hirkata.

Waan amansiisaa ta'e garuu hin mirkanoofne: Packing principle wal-fakkaatu solid-state upconversion maateriyaalota fooyya'aa uumu; related metal-free sensitizer sirnoota comparable raawwii argachuuf optimize ta'uu; films akkanaa fuuldura photocatalysis yookaan solar-chemistry fayyadamoota keessatti gargaaraa ta'uu.

Waan hin agarsiifne: Working device; faayidaa qabu solar-fuel yookaan photocatalytic bu'aa; outdoor durability; ol-aanaa waliigalaan solar-spectrum efficiency; economic practicality; chromophores kam irratti iyyuu hojjetu waliigalaa recipe.

Daangaawwan ijoo: Laaboraatoorii film, maateriyaalii sirna addaa, modest absolute quantum yield, best-performing haala keessatti iridium donor, to'atame excitation wavelength, device-level demonstration hin jiru. “Sunlight-level” excitation band naannoo keessaa dha, guutuu solar-technology himannaa miti.

Dubbisaan waliigalaa amanamummaa hammam qabaachuu qaba? Tested sirna keessatti maateriyaalii qophii solid-state mul'ataa-to-UV TTA-UC fooyyessu irratti amanamummaa guddaa, fi

bu'aa scientifically hiika qabu ta'uu irratti amanamummaa guddaa. Deployable solar technologytti dhiyaachuu irratti amanamummaa gadi-aanaa. Stance sirrii: maateriyaalota advance clever fi dhugaa — fayyadama seenaa baay'een ammoo fuuldura jira.

Maddoota

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Supplementary Information

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