

H AND J AGGREGATES

1. Introduction

1.1 Definition of H and J aggregates

The self-association of dyes in solution or at the solid-liquid interface is a frequently encountered phenomenon in dye chemistry owing to strong intermolecular van der Waals-like attractive forces between the molecules. The aggregates in solution exhibit distinct changes in the absorption band as compared to the monomeric species. From the spectral shifts, various aggregation patterns of the dyes in different media have been proposed. The bathochromically shifted **J-bands** (J for Jelly, one of the first workers who investigated these shifts) and hypsochromically shifted **H-bands** (H for hypsochromic) of the aggregates have been explained in terms of molecular exciton coupling theory, i.e., coupling of transition moments of the constituent dye molecules.

The aggregates that exhibit J-bands in their absorption spectrum are called J aggregates and H aggregates exhibit these H bands.

1.2 Shifts in the absorption spectrum

Bathochromic shift is a change of spectral band position in the absorption, reflectance, transmittance, or emission spectrum of a molecule to a longer wavelength (lower frequency). This can occur because of a change in environmental conditions: for example, a change in solvent polarity will result in solvatochromism. **Solvatochromism** is the ability of a chemical substance to change color due to a change in solvent polarity. Negative solvatochromism corresponds to hypsochromic shift, positive solvatochromism corresponds to bathochromic shift with increasing solvent polarity. The sign of the solvatochromism depends on the difference in dipole moment of the molecule of the dye between its ground state and excited state.

A series of structurally related molecules in a substitution series can also show a bathochromic shift. Bathochromic shift is a phenomenon seen in molecular spectra, not atomic spectra - it is thus more common to speak of the movement of the peaks in the spectrum rather than lines.

$$\Delta\lambda = \lambda_{\text{observed}}^{\text{state2}} - \lambda_{\text{observed}}^{\text{state1}}$$

where λ is the wavelength of the spectral peak of interest and

$$\lambda_{\text{observed}}^{\text{state2}} > \lambda_{\text{observed}}^{\text{state1}}$$

It is typically demonstrated using a spectrophotometer, colorimeter, or spectroradiometer.

Bathochromic shifts are often referred to as **red shifts**. Although this usage is considered informal, it is often used in the literature. It has no relation to Doppler shift or other wavelength-independent meanings of redshift.

Hypsochromic shifts are often referred to as **blue shifts in photochemistry**. Blue shift is the phenomenon that the frequency of an electromagnetic wave (such as light) emitted by a source moving towards the observer is shifted towards the blue side of the electromagnetic spectrum (that is, its wavelength is decreased, or its energy is increased).

1.3 One dimensional assembly of H- and J- aggregates in the solution

Extensive studies on J- and H-aggregates have resulted in the proposal that these aggregates exist as a one-dimensional assembly in solution that could be in (a) brickwork, (b) ladder, or (c) staircase type of arrangement. The pattern of the assembly is shown in the figure 4.

Maskasky based on the study of J-aggregates proposed the brickwork model of polymethine dyes on silver halide grains by polarized fluorescence microscopy.



Fig1. Schematic representation of the different arrangement of cyanine dyes in the solid surface and in solution.

2. Theory

2.1 The exciton theory

The aggregation behavior of cyanine dyes has been studied extensively since these are the best - known self-aggregating dyes. It is generally agreed that both H- and J-aggregates are composed of parallel dye molecules stacked plane-to-plane and end-to-end and form two-dimensional dye crystals.

When Scheibe and Jelly noticed J bands in PIC organic molecules, they called it a "communal" state of the dyes []. Later Frank and Teller [] noticed the similarity of these excitations with the Frenkel excitation that was proposed for molecular crystals.

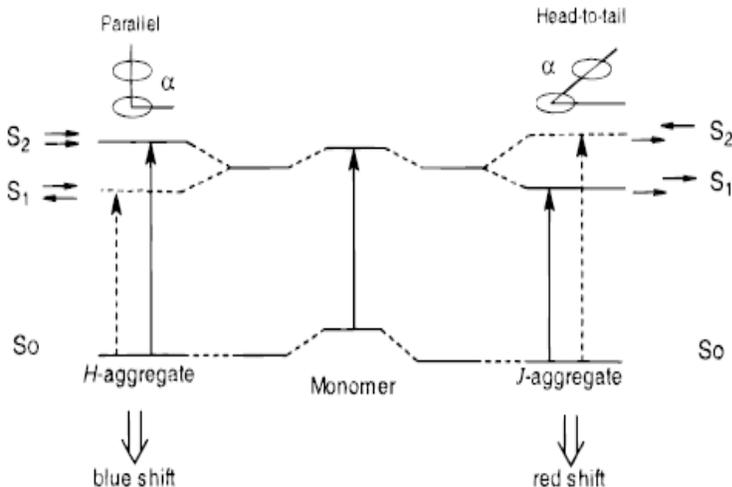


Fig 2. Schematic representation of the relationship between chromophore arrangement and spectral shift based on the molecular exciton theory.

According to exciton theory the dye molecule is regarded as a

point dipole and the excitonic state of the dye aggregate splits into two levels through the interaction of transition dipoles.

The dye molecules may aggregate in a parallel way (plane-to plane stacking) to form a sandwich-type arrangement (H-dimer) or in a head-to-tail arrangement (end-to end stacking) to form a J-dimer.

A transition to the upper state in parallel aggregates having parallel transition moments (acridine orange, Figure 2) and to a lower state in a head-to-tail arrangement with perpendicular transition moments (PIC, Figure 3) leads to hypsochromic (red) and bathochromic (blue) shifts, respectively (Figure 1).

Fig 3 Acridine orange

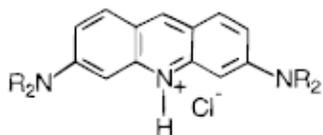
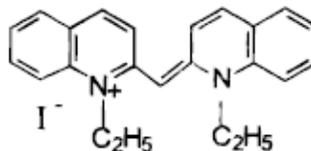


Fig 4 PIC



The angle between the line of centers of a column of dye molecules and the long axis of any one of the parallel molecules is called the '**angle of slippage**', Large molecular slippage ($R < 32^\circ$) results in a bathochromic shift (J-aggregate), and small slippage ($R > 32^\circ$) results in a hypsochromic shift (H-aggregate).

Important point to note is that, the exciton theory is valid only when the interaction between orbitals of constituent molecules is negligible.

2.2 Coherent exciton scattering (CES) theory

When Scheibe a Jelly noticed J bands in PIC organic molecules, the called it a "communal" state of the dyes [2]. Later Frank and Teller [3] noticed the similarity of these excitations with the Frenkel excitation that was proposed for molecular crystals Although exciton theories we able to predict the position of the polymer band peak, the unique feature of the narrow-ness of the J band was not fully described. As for H- aggregation where the vibrational peaks are noticed no simple theory existed. The CES approximation is a one-band exciton model. It depends on the precise absorption characteristics (including the vibrational peaks) of the monomer forming the aggregate and the coupling constant between the different monomeric units. It aims to relate the shape of the absorption peak of monomeric unit to the absorption of the aggregate. For this band shape functions $G(E)$ for polymer and $g(E)$ for monomer are used [4].

This is known as the Green function operator given by,

$$G(E) = \frac{1}{E - H + i\delta}$$

Where H is the complete Hamiltonian of the system

And,

$$g(E) = \frac{1}{E - H_0 + i\delta}$$

H_0 – Hamiltonian of the monomer

H and H_0 are related by

$H = H_0 + V$ where V is the monomer-monomer electronic interaction

V is also known as the coupling constant (C) which is known for a given system. $C = 2J$ for a dimer system where J is the transition dipole–dipole interaction between nearest neighbors.

From this it follows that,

$$\langle G(E) \rangle = \langle g(E) \rangle [1 - C \langle g(E) \rangle]^{-1}$$

The green function operator is known to have the following properties [5]

1. The imaginary part of g gives the shape of the band
2. A one-band theorem [] shows that C is precisely the difference between the mean absorption energy of the polymer band the mean absorption energy of the monomer band
3. The real and imaginary part of both the green functions are related by

$$\text{Re}f(E) = \frac{1}{\pi} P \int_{-\infty}^{\infty} \frac{\text{Im}f(E')}{E' - E} dE' \quad \text{Where f can be both G and g}$$

4. Both the functions show absorption peaks at the poles of their imaginary part of the function.

For the polymer, it implies that the absorption happens when $g(E) = 1/C$. Since C is real, we can say that $\text{Re}(g) = 1/C$

Lets consider the simple case of dye TDBC. The monomer shows a single broad peak and forms a J aggregate which is narrow and shows no absorption in monomer region.

C value can be calculated from the graph.

Using the monomer absorption band, $\text{Im}g$ (g (E)) can be calculated.

And using the relation the real part is evaluated.

A plot is made between $\text{Re} (g)$ and E . The point where this curve intersects the line $1/C$ should give our adsorption peak, according to our theory.

We see that the graph of the real part if g intersects the line corresponding to $1/C$ at two points of which one is in the range of monomer adsorption while the other is red shifted (575nm).

Strong narrowing of the J-band is expected only when C is large enough to shift the pole to regions where the monomer does not absorb. Physically, C larger than the monomer bandwidth is the strong-coupling case where the exciton transfer time is much shorter than the vibrational relaxation time. Thus the 575 nm point is manifested as a peak in the polymeric aggregate while the lower wavelength point is seen only as a shoulder.

To explain H-aggregation, it is necessary to also look at vibrational energies [5]

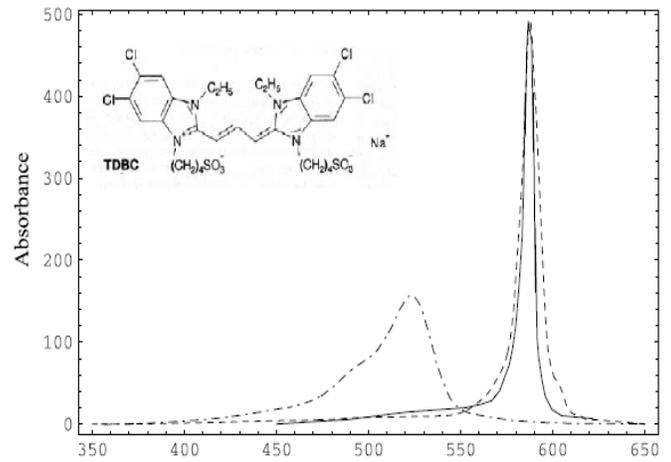


Fig 5. The absorption spectrum of the dye TDBC
 Dot-dash line: the monomer spectrum.
 Continuous line: the J-aggregate spectrum.
 Dashed line: the theoretical J-aggregate spectrum, with $C = 2416 / \text{cm}$.

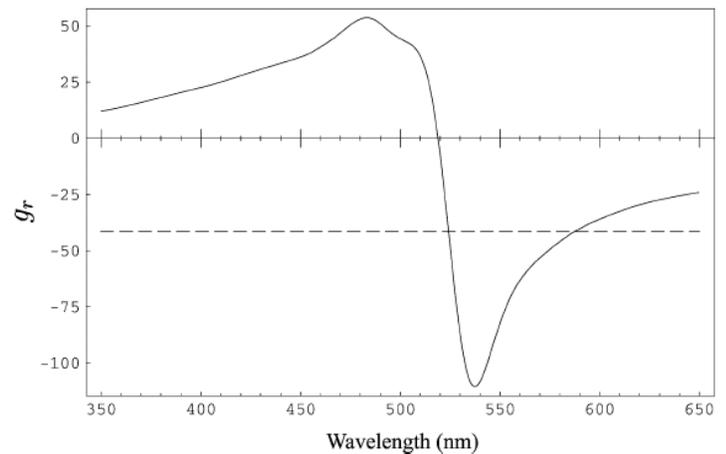


Fig 6 The real part of the monomer function $g(E)$ as a function of wavelength in nm.
 The horizontal line denotes the value of $1/C$ corresponding to $C = -2416 / \text{cm}$.

For the dye monomers considered, single vibration progression is a good approximation, that is, the monomer absorption band is described by,

$$\text{Im } g(E) = -\pi \sum_{j=0} |f_j|^2 \delta(E - \epsilon_j)$$

Where $|f_j|^2$ are Frank Condon factors for transition from vibrational ground state to j th state with energies ϵ_j

In our previous definition of g (where we had only one energy level) if we sum over all the energy states now available, we get

$$g(E) = \lim_{\delta \rightarrow 0} \sum_{j=0} \frac{|f_j|^2}{E - \epsilon_j + i\delta} ; \text{ Where } f_j \text{ s are known to follow Poisson distribution.}$$

Using our same procedure as before for a given monomer band with different positive (Blue shift; H-aggr) and negative (Red shift; J-aggr) values for C , it is possible to replicate the behavior of real systems.

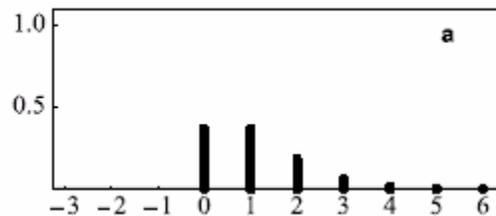
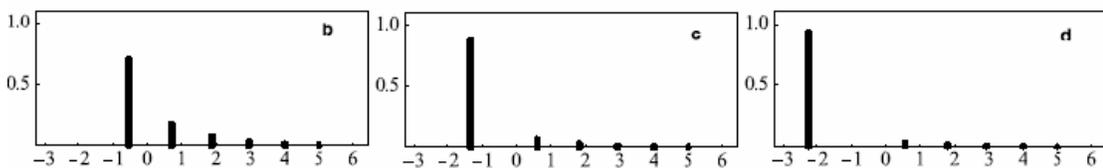
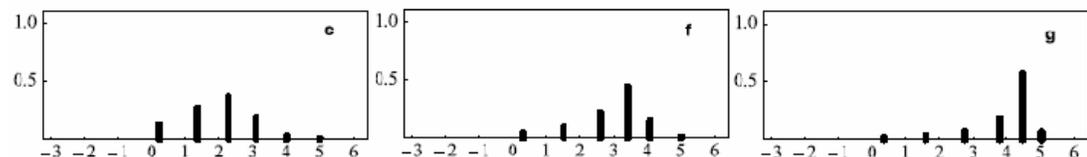


Fig 7. Model monomer band

For $C = -1$ (b), -2 (c), -3 (c) J bands (red shifted, narrow)



For $C = +1$ (e), $+2$ (f), $+3$ (g) H bands (blue shifted, broad)

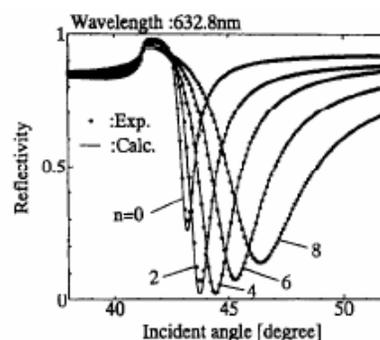


3. Properties

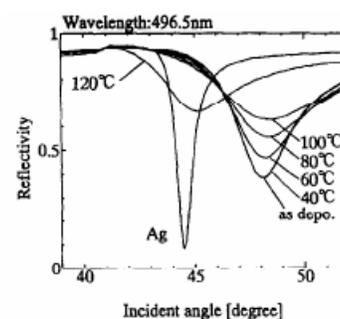
The H & J-aggregate molecules are known to show many interesting novel properties like linear & nonlinear optical(NLO) response, photoelectric, photorefractive, photochromism, superradiance, Superfluorescence, Electroluminescence, photoluminescence, attenuated total reflection (ATR) etc. which have many applications in major fields of science.

3.1 Attenuated total reflection properties

The attenuated total reflection (ATR) properties were studied for H aggregation of annealed squarylium (SQ) Langmuir-Blodgett films on thin Ag layers. The ATR properties were found to vary as a function of the incident angle of the laser beam and number of LB monolayers. The resonant angles at the dips increase with increasing number of monolayers. The complex dielectric constants of the LB films (uniaxial anisotropic dielectrics) were determined by fitting the theoretical ATR curves to the experimental curves. The complex refractive indices were also calculated as the square root of the complex dielectric constants.



Attenuated total reflection (ATR) measurements in visible light can be used to analyse accurately the surface of ultrathin films of dielectric materials (several nanometres thick) with complex dielectric constants, i.e. the refractive indices and thickness of the ultrathin films can be obtained from ATR^[5] measurements.



3.2 Super-radiance

Cooperative emission phenomena, such as superradiance, superfluorescence, amplified spontaneous emission, stimulated emission, and

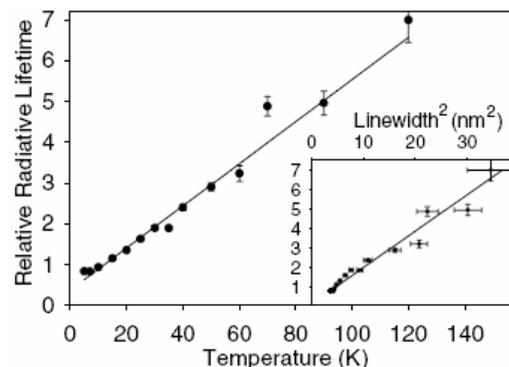


Fig 10 Relative radiative lifetime (τ_{rad}) of the 0-0 emission vs temperature.

lasing, are of great interest to understand the physics of collective phenomena.

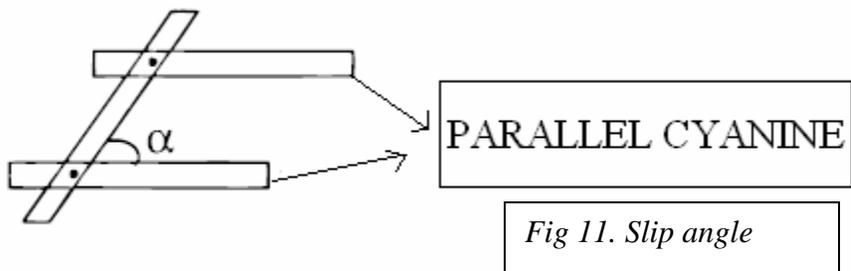
Time resolved photoluminescence measurements show a linear correlation between the radiative lifetime (τ_{rad}) of the purely electronic exciton recombination and the inverse of the number (NC) of the coherently emitting dipoles. The *radiative* lifetime of the exciton on the J-aggregates is temperature dependent; it increases with temperature approaching the monomer's radiative lifetime at high temperatures. This superradiance property has many applications^[6].

4. Detection of H and J aggregates

In order to do any useful science on the H and J aggregates we first need to identify them. There are several techniques which are available to do the experiments and detect these aggregates like fluorescence microscopy etc. The paper "*In Situ Detection of Birefringent Mesoscopic H and J Aggregates of Thiocarbocyanine Dye in Solution*" by Hiroshi Yao et al [7], has utilized the property of structural differences in the H and J aggregates which give rise to difference in the optical properties. First of all we will go through some of the optical properties of H and J aggregates which can be further use to detect and differentiate these aggregates.

As described above H and J aggregates have their optical properties according to their structural packing. Actually the difference in structure is due to the different slip angles of the stacked molecules. The slippage angle can be defined as the angle between long axis (line passing through the center of the aggregates or parallel to it) and one of the parallel molecule.

It is generally agreed that both H- and J-aggregates are composed of parallel dye molecules stacked



plane-to-plane and end-to-end and form two-dimensional dye crystals molecule,

according to exciton theory, is regarded as a point dipole. When molecules (or chromophores) are parallel aligned, two new excitonic bands are generated according to a simple exciton theory: one with higher energies and the other with lower than the monomer energy level as mentioned in the initial parts of the report. In H aggregates, the lower state is much stabilized. So the transition from the excited state to the ground state is very fast and happens mostly between the excitonic bands with vanishing dipole moments as a result of which most of the energy losses are non-radiative like thermal losses. Due to this reason the H aggregates have very low fluorescence which is difficult to measure by regular techniques. The H-aggregates have large Stokes shift with low fluorescence yield.

In J aggregates, transition only to low energy states are allowed and as a consequence, J aggregates are characterized by little Stokes shift fluorescence with a high quantum yield.

Fluorescence microscopy is the technique which has been widely used to study the dynamic processes and since J aggregates have high fluorescence quantum yield and hence their structure can be studied using fluorescence microscopy. But this is not the case with H aggregates since they have low quantum yield. There is one more technique which can prove to be useful which is known as "Polarized light microscopy". This technique exploits the property of optical anisotropy of the material. As we will see in the following discussion that due to well ordered molecular alignment of J aggregates, it is found to be active for this microscopy. H aggregates form mesoscopic sized supra molecular assemblies having regular molecular alignment with strong *birefringence* and hence their aggregates should be detected directly using polarized light microscopy.

In the remaining part of this section we will discuss about the experimental result obtained in the paper by Hiroshi Yao et al [1], which can be useful for further analysis.

4.1. Spectroscopic Characterization of J and H Aggregates of TCC Dye in Solution

The diagram shows the absorption pattern of the TCC dye with varying concentration.

The spectrum from the 10^{-3} mM comes from the TCC monomer. As the dye concentration is increased to

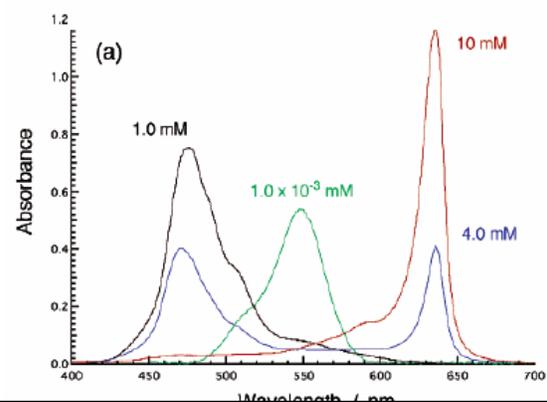


Fig:12 Absorption spectra of thiocarboaniline (TCC)

1mM, the spectrum exhibits a relatively blue shifted curve (475 nm) in comparison to the monomer peak (548nm). This blue shifted spectrum is commonly assigned to H-aggregates. During the experiment in detecting H-aggregates, the authors found many intermediate spectrums which are very complex in nature and points towards the presence of polymeric species which in turn says that H aggregates may be polymeric.

When the concentration is further increased a sharp and intense *J* band (636 nm) red-shifted to the monomer peak, appeared at above ~ 3.0 mM TCC together with the *H* band. The spectrum at [TCC] = 4.0mM indicates the presence of both *H* and *J* aggregates in solution. The spectral change arises from an increased amount of *J* aggregates at the expense of a decreasing *H* aggregate. At a higher dye concentration (10 mM), the absorption spectra solely exhibited the *J* band.

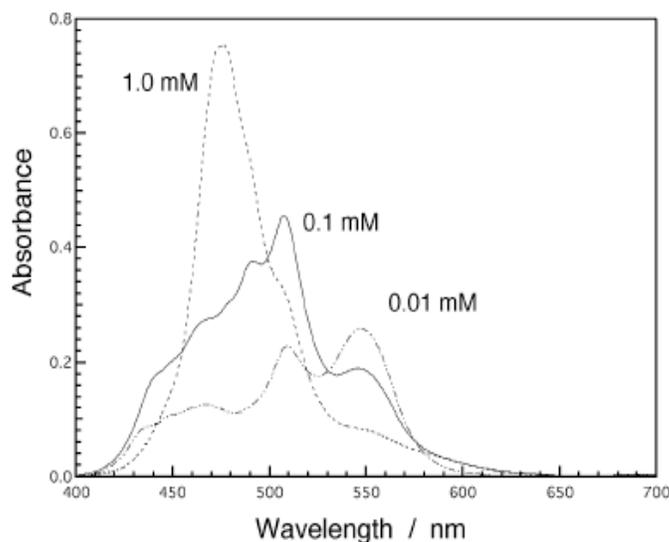


Fig:13 Absorption spectra of thiocarbocyanine (TCC) dye in aqueous solution at 0.01, 0.1, and 1.0

4.2. Characterization of Mesoscopic Supramolecular *J* Aggregates by Fluorescence Microscopy

Since the *J* aggregates can have high quantum yield, their morphologies can be observed and studied using Fluorescence.

At a low dye concentration of 1.0 or 2.0 mM, no characteristic images (or dark images) could be seen, indicating no *J* aggregates in the solution. At 3.0 mM, dot like emissive fragments in Brownian motion were observed. At 3mM concentration of TCC the dot like

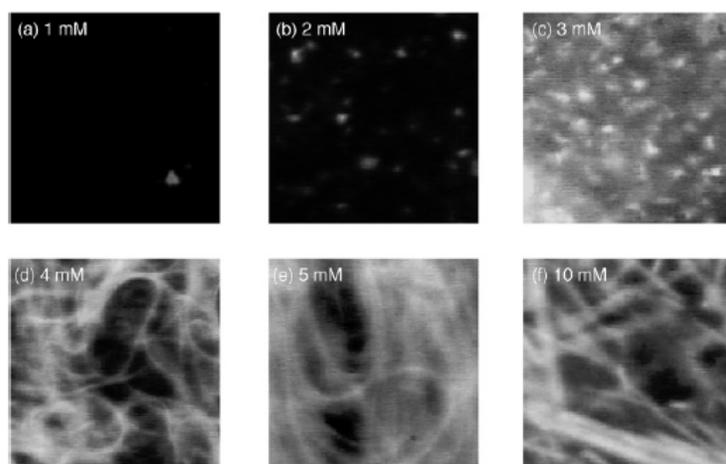


Fig 14 Representative fluorescence micrographs of TCC *J* aggregates in aqueous solution.

emissive fragments distributed are the TCC *J* aggregates. Upon increasing the dye concentration, the morphology of the *J* aggregate was drastically transformed. Mesoscopic fiber morphology was clearly observed at concentrations of 4.0 and 5.0 mM. The length of the fiber was several tens of micrometers, while the width was very narrow in sub-micrometers. This fibrous structure probably comes from anisotropic interactions between TCC molecules in the aggregate. With further increase in the concentration of the TCC, the morphology of the fibers become straighter as compared.

Instead of using unpolarized light, if we use polarized light, then we can observe the direction of the molecular alignment in the *J* aggregate fiber as excitation depends on the orientation of the transition moment of the aggregate. The bright images means the excitation polarization was parallel to that of the long axis of the fiber, whereas the dark image could be seen when the direction of the excitation polarization is perpendicular to that of the long axis.

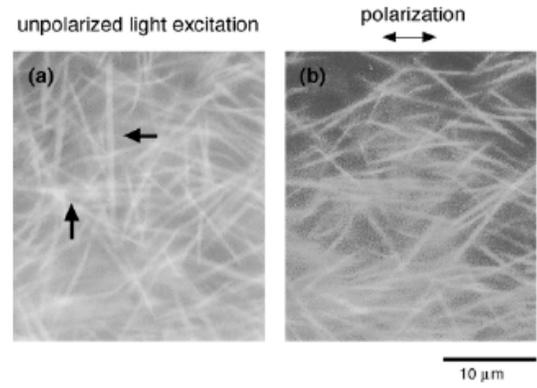
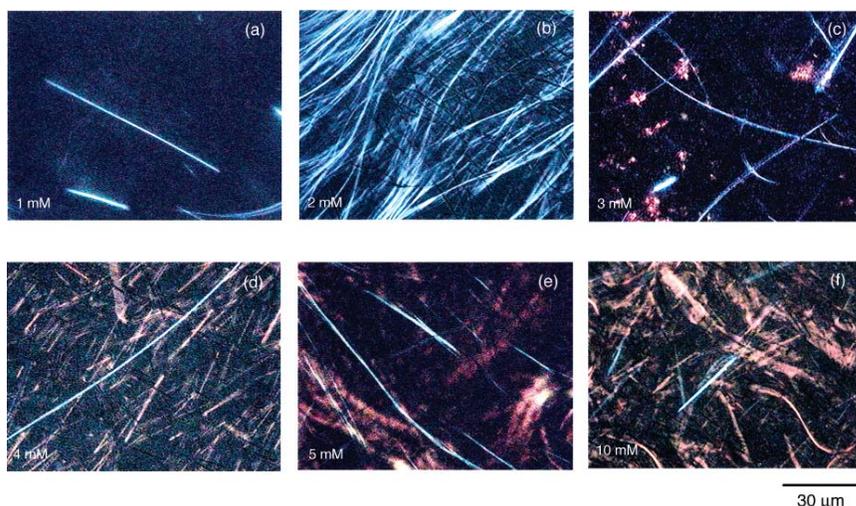


Fig 15: Fluorescence micrographs of fibrous *J* aggregates obtained by using Unpolarized and (b) linearly polarized light excitation.

4. 3. Birefringence property of aggregates

Birefringence is formally defined as the double refraction of light in a transparent, molecularly ordered material, which is manifested by the existence of orientation-dependent differences in speed of light (or refractive index), i.e. optical anisotropy. The term anisotropy refers to a non-uniform spatial distribution of properties, which results in different refractive index for ordinary wave and extra ordinary wave when specimens are being observed from several directions. One can detect optical anisotropy using polarized-light-microscopy, since it can distinguish between isotropic and anisotropic regions. To detect this property, one can put sample of aggregate between cross-coupled analyzer and detector (both are polarizer). For different concentration of monomer one can get images of *J* and *H* aggregates. It shows property like shown in figure.



For low concentration (1mM to 2mM) it forms H aggregate which has blue color. With increase in concentration it start making J aggregates (since both are in equilibrium) which has red color. Since H aggregates have blue region of absorption and for J aggregates red region of absorption, one will not expect this type of color behavior. The observed color differences can be explained via by following mechanism. As light pass through anisotropic specimen, different polarized light (with respect to anisotropic specimen axis) experience different path length insight material. So there will be a path difference at the analyzer. The analyzer in the microscope recombines two components of light traveling in the same direction producing an intrinsic interference color of light. Therefore, the interference color strongly depends on the retardation (or path difference), as a function of the sample thickness and the degree of birefringence. If retardation is different between the *H* and *J* aggregates, the observable interference colors also differ from each other. Quantitatively, the intensity of observable light through interference is proportional to the square of the amplitude of two recombined waves (that is, proportional to, $\sin^2(\pi.R/\lambda_0)$) where R and λ_0 are the retardation and the wavelength of light, respectively). At $R < 150$ nm (for H aggregates), the value of $\sin^2(\pi.R/\lambda_0)$ monotonically decreases with increasing λ_0 in the visible region (350- 900 nm), whereas that oscillates from 0 to 1 at $R > 150$ nm(for J aggregates). Therefore, it is conceivable that a pale-blue color of the *H* aggregate is caused by a relatively small retardation of the aggregate (<150 nm). This also implies that the contribution of interference to the observable colors is larger than that of the absorption of the *H* aggregates at 475 nm. On the other hand, we have detected the reddish *J* aggregates despite the intense absorption of red light at 636 nm. This is probably due to a large retardation of the *J* aggregates (>150 nm), and the resulting lack of blue-light region would produce a characteristic interference color of the aggregates.

4. 4. Topographic Study of the Fibrous H Aggregates

Below shows the AFM image of a fibrous H aggregate along with a cross-sectional profile. The fibers are 30-100 nm wide and 10-15 nm high. The tip of the fibers was branched, indicating that the thick fiber is a bundle of primary thin fibers.

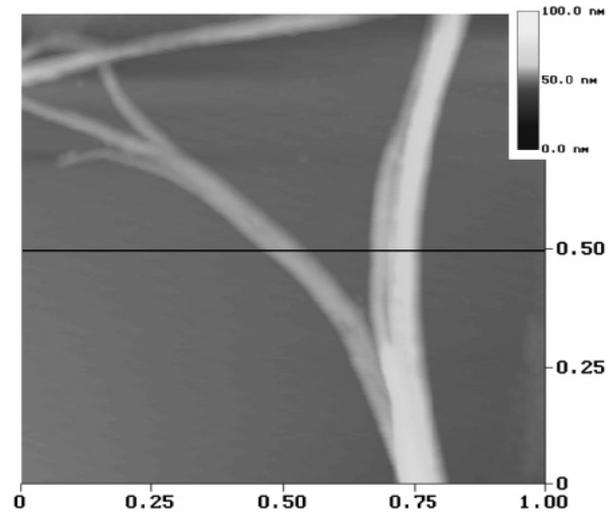
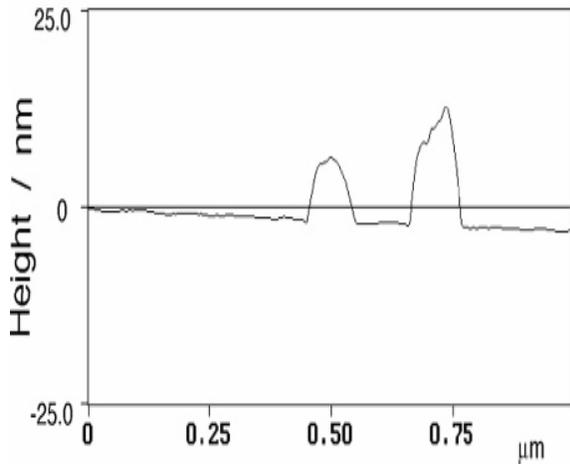


Fig 17: Typical AFM image and a cross-sectional profile of a fibrous H aggregate

5. Application

The speed and capacity of information transmission are increasing rapidly. To establish T bps (Tera bits per second) information network systems based on optical time division multiplexing (OTDM), femtosecond optical materials and devices are required as key factor. For this investigation is done on inorganic compounds like GaAs semiconductors etc. and organic systems like conductive polymers and J-aggregates of certain dyes. The J-aggregates of certain dyes have been shown to exhibit ultrafast and high nonlinear optical responses. The lifetime of excited states of J-aggregates is of order of picoseconds, much shorter than that of quantum wells (of order ten nanoseconds) of inorganic semiconductor materials thus showing their superiority in their applications.

5.1 Optical Switches

In telecommunication networking, the wavelength of optical pulses used is around 1.3 or 1.55 μm because of the high transmittance of optical fibers at these wavelengths. Thus, optical switching compounds that can exhibit a fast optical response at wavelengths of order 1.55 μm are of great interest.

The J-aggregates of Squaraines, 1,3-disubstituted derivatives of squaric acid, display strong absorption spectra with absorption maxima at 780 nm. For further shifting the absorption to longer wavelengths the p-conjugation within molecules is extended by enhancing the strength of the donor groups. This is done by introducing two dialkylamino groups or two alkoxy chains.

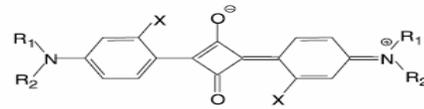


Fig 18: Squarylium (SQ)

The absorption maxima of thus formed compound from alkoxy chains is found to be at 1168 nm continuing until 1600 nm. The nonlinear absorption coefficient b of this was found to be approximately $1 \times 10^7 \text{ mW}^{-1}$, and it showed ultrafast optical response with time constant of 98 fs, which indicates its good applicability to optical switches working in the infrared region^[8,9].

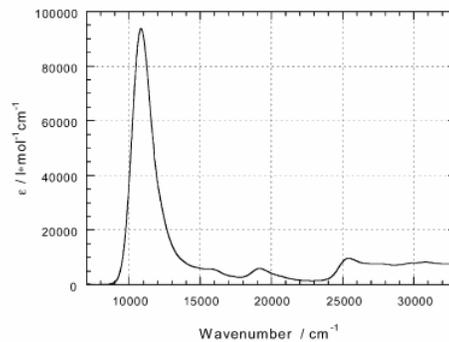


Fig 19:
UV/vis/NIR spectrum

5.2 Serial-to-parallel pulse converter (De-multiplexer):

Demultiplexer's are used to convert a high-speed data stream into multiple low-speed data streams. Spincoated films of (Squarilium) SQJ-aggregates can be used for Demultiplexing. A large area of SQJ-film can be regarded as ultrafast optical shutter array when a gate pulse exists and reduces within 1 ps increasing the transmission of signal pulse.

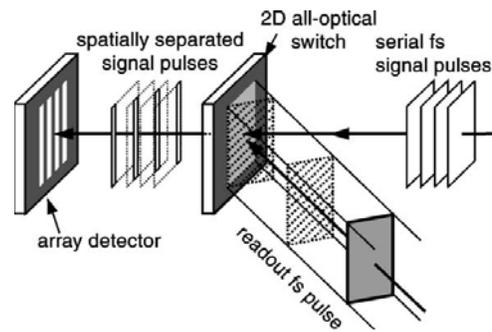


Fig 20: Experimental setup for parallel demultiplexing operation

A multi-output demultiplexing operations for T bps pulses were performed by irradiating a series of 4fs pulses of 1 ps interval (corresponding to 1 THz repetition rate) onto SQJ-film for signal pulses synchronized with a femtosecond gate pulse at a finite angle as shown in above figure. Because the spatial thickness of femtosecond pulses is less than 100 μm , each signal pulse meets a gate pulse at a different area on a SQJ-film. At each crossing area, the SQJ-film works as an optical shutter and each signal pulse is detected from the different area of the film, as successive pulses do not pass through the same area of the film. Absorption change of the SQJ-film recovers almost completely within 1 ps.

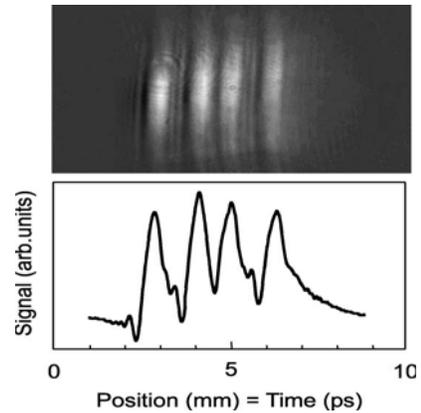


Fig 21: Output profile of differential image by CCD camera

Demultiplexed signals were detected by CCD camera as a differential image of signal pulses between with and without a gate pulse. Four clear output signals were observed at different area on CCD. Each signal has sharp rising edge and slightly gentle decay tail. This corresponds to the fact that, in the case of absorption of SQJ-film, the absorption reduction occurs within a few femtoseconds but the relaxation to half a maximum requires about 300 fs. A little roughness observed in the profile can be attributed to the interference among the diffraction lights by apparatus edges^[10,11].

5.2 Photoelectrical effect

Compounds of J-aggregates show photoelectric sensibility in the region of action of He-Ne laser (633 nm) and are known to have the highest third-order macroscopic electronic susceptibility (χ^3). This property can be used to change the Redox potentials of certain materials like polymers of aromatic polyimide (API) by doping with J-aggregates of the carbocyanine dye. The J-aggregates of the dye sensitize the polymer layers to light of the He-Ne laser. To know the mechanism of the photo-generated effect, the hole and electron drift mobility in the layer of API doped with the dye and without the dopant was measured. It is known that only hole drift mobility is observed in the API layers without an additive. The addition of Dye did not change hole mobility but caused electron drift mobility. The electron transport in the layers is due to J-aggregates of Dye.

The redox potential of the material can be selectively varied by changing the composition of the J-aggregate dye^[12].

5.3 Heterojunction Photovoltaic devices

Cyanine dyes are well known as photovoltaic sensitizers because of their possibility to form J aggregates with highly delocalized excitons. It is shown that a carbocyanine dye acts as donor in conjunction with buckminsterfullerene (C60). Due to its high electron affinity, the cyanine dye can also act as acceptor when using copoly(dicyano-phenylvinylene-triphenylamine) as donor. Due to the high extinction of cyanine dyes it is possible to use thin films for efficient light harvesting. In a photovoltaic cell, when the cyanine layer is sandwiched between the polymer donor and the C60 acceptor, incident photon to current conversion efficiencies(IPCE) greater than 10% are observed which is very high compared to other photovoltaic cells. The cyanine dye layer acts as both donor and acceptor increasing the efficiency of the photovoltaic cell. So far, cyanine dyes have been used as sensitizer only in Gratzel type solar cells. The possibility of using cyanine dyes at the same time as donors and acceptors is a promising strategy to improve conversion efficiency^[13].

5.4 Photography

Photoinduced energy and electron transfer from adsorbed dyes to a silver halide microcrystal is the fundamental step in the imaging process of photography. The dye enables silver halide to be sensitive to the visible light, which is called the spectral sensitization. J-aggregates of cyanine dyes are especially useful since they adsorb very well on AgBr microcrystals and realize color selective sensitization with its strong and narrow absorption bands. The sensitization of the AgBr microcrystals can be increased towards a particular colour (wavelength) by choosing the adsorbed dye appropriately^[14].

6. Conclusion

The formation of H& J aggregates is explained by considering the electronic states of the aggregate molecules using exciton theory and CES theory. The detection and preparation of some of these aggregates is given while focusing on their various importance properties like electronic states, linear and nonlinear optical properties, photoelectric, photorefractive, superradiance, attenuated total reflection etc. Application of these properties in various devices is studied & the

possibility of these aggregate molecules for constructing supramolecular machines is shown to be promising.

7. References

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