

Initial models suggest a two-stage rupture, the first one being about 300 km to the northwest from the hypocentre during the initial 100 s (Yuji Yagi, 2005; <http://iisee.kenken.go.jp/staff/yagi/eq/Sumatra/Sumatra2004.html>). The second slower rupture started about 100 s after the initial break. Much of the ongoing aftershock activity in the Andaman–Nicobar arc seems to be associated with this slow rupture. These initial models would be modified as more data are being analysed. We believe that the question whether these are in fact multiple ruptures associated with independent segments, needs to be resolved.

Implications for future

Recognizing the threat regarding earthquakes originating from the Andaman–Nicobar arc, various studies have been initiated in this region for quite some time. In addition to seismic monitoring, there are programmes to monitor plate deformation using GPS data. Pre- and post-earthquake GPS data would be most crucial to model the displacement caused by this great earthquake, the largest, to have occurred since the advent of the GPS technique to monitor plate deformation. Spatial-temporal pattern of subduction earthquakes needs to be understood in great detail and this gap-filling earthquake provides an opportunity to initiate such studies. A causal relationship and a 50-yr gap between great earthquakes and rejuvenation of magma chambers has been noted, a correlation has been suggested between the 1941 Andaman earthquake and the 1991 Barren Island volcanic eruption

(Rajendran *et al.*⁶, and references therein). How this great earthquake would affect the stability of the magma chambers is another issue that needs to be addressed, particularly in the context of massive volcanic eruptions such as the 1883 Krakatoa. The other question concerns the threat from tsunamis on the Indian coast, which was generally not taken much into account in hazard-assessment scenarios.

Perhaps, the most important question that the December 2004 earthquake has triggered is whether the northern segments of the arc and parts of the Himalaya, which have not ruptured in any major earthquake during the last 55 years, will be the next candidates. This has already been pointed out by some workers (see <http://cires.colorado.edu/~bilham/indonesiAndaman2004.htm>).

Scientifically, this earthquake would provide a wealth of data that would be useful in studying the stress release, pattern of displacement and slip on various segments. These studies have great implication for future seismic-hazard evaluation. Being the first known great plate boundary earthquake in the Andaman–Sumatra region, the plate dislocations that this event may have caused in other parts of the arc, notably the unbroken segments to the north, need to be monitored closely. While the reoccupation of the existing benchmarks in the Andaman–Nicobar–Sumatra regions will help model the coseismic and post-earthquake stress relaxation, there is a compelling need to strengthen monitoring of the northern segments, including NE India.

Clearly, we had no strong evidence to foresee that an earthquake of M 9 could occur in the Sumatra arc and its tsunami run-up could reach even the southwest coast (Kerala) of India. However, various studies in this region have implied a locked fault zone, with potential for great earthquakes. This earthquake reminds us once again about how much we underestimate the threats from earthquakes both within and outside the Indian territory. The Indian coast is located far enough to get 1–2 h warning from earthquakes originating from this active plate boundary. The 26 December 2004 earthquake calls for more focused studies on earthquake sources in India and the neighbourhood, and estimation of direct and indirect threats posed by them.

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RESEARCH NEWS

A 'SOUND' method for synthesis of single-walled carbon nanotubes under ambient conditions

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The discovery of carbon nanotubes (CNTs) by Iijima¹ in 1991 is a milestone in the study of different forms of carbon and CNTs have been recognized as the quintessential nanomaterial². Potential applications of CNTs are well documented^{3–6}. Recently, an elegant and cost-effective synthesis of multi-walled carbon nanotubes (MWCNTs) has been proposed by Kang *et al.*⁷ and was also reported in this journal⁸. It will be of interest to know whether such a simple method is possible for the synthesis of single-walled carbon nanotubes (SWCNTs), which were first reported^{9,10}

in 1993. SWCNTs can have diameters varying from 1 to 3 nm and length of 100 μ m and they are synthesized by the same methods employed for MWCNTs, viz. electric arc discharge, laser ablation, catalytic synthesis⁴ and chemical vapour deposition⁵. The notable difference is that the presence of a metal catalyst is essential for the growth of SWCNTs. Several other strategies have been explored for the preparation of SWCNTs. A recent account by Rao and Govindaraj¹¹ describes the synthesis of CNTs from organometallic precursors. Rao and co-workers have

also shown that pyrolysis of dilute acetylene-metalocene, $M(C_2H_2)_2$ (M = Fe, Co, or Ni) mixtures at 1100°C yields isolated SWCNTs¹¹.

Scientists from Samsung Advanced Institute of Technology, Korea have recently achieved a breakthrough in the synthesis of SWCNTs by developing a sonochemical route to SWCNTs of high purity in a liquid solution at atmospheric pressure and room temperature, without the necessity of any specialized equipment and starting with the organometallic precursor, ferrocene¹².

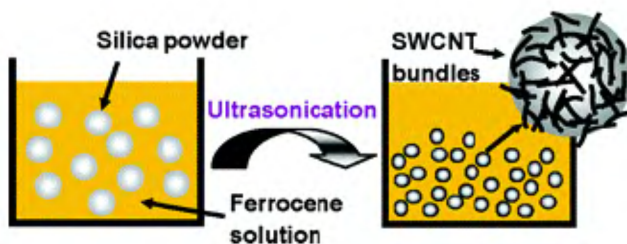


Figure 1. Schematic of sonochemical route to SWCNTs. Silica powder is immersed in the solution (ferrocene–xylene mixture). Ultrasonication was carried out for 20 min at room temperature and atmospheric pressure. Sonication produces high-purity SWCNTs on the surface of silica powder (reproduced from Jeong *et al.*¹² with permission from Wanjun Park).

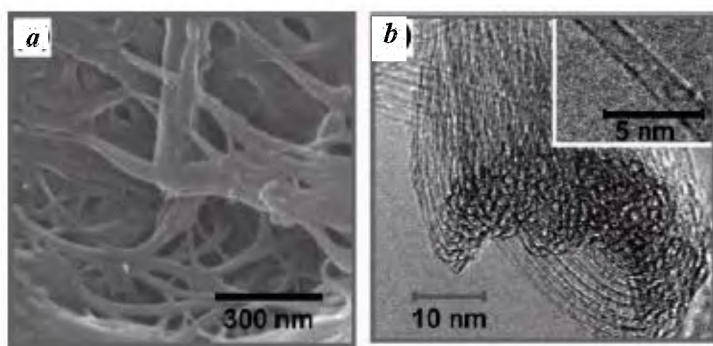


Figure 2. *a*, SEM image of SWCNT bundles on polycarbonate filter membrane. *b*, HR-TEM image of SWCNTs. Most SWCNTs exist in bundles. For measurement of diameters of SWCNTs, individual SWCNTs (inset) are also imaged by HR-TEM (reproduced from Jeong *et al.*¹² with permission from Wanjun Park).

The method involves addition of silica powder (diameter 2–5 μm) to a solution of 0.01 mol% ferrocene in *p*-xylene followed by sonication by a $\frac{1}{2}$ " titanium tip probe (200 W) at atmospheric pressure and room temperature for 20 min. Jeong *et al.*¹² observed that silica powder broke into small pieces of length below several hundreds of micrometres triggered by ultrasonic irradiation and the colour of the silica powder changed to grey, indicating a carbon deposition on its surface. Figure 1 depicts the sonochemical method for SWCNT growth. Field emission scanning electron microscopy of the powder collected on a filter membrane revealed that fibre-like structure exists on the surfaces of silica powder and the direct evidence for the formation of Fe catalyst on silica powder was provided by HR-TEM energy-dispersive X-ray spectra of the samples. While ferrocene and *p*-xylene served as precursors of Fe catalyst and carbon sources respectively, silica powder provided a nucleation site for SWCNT growth (ferrocene can also be a source for carbon).

The removal of silica powder using HF yielded fibre-like structures (Figure 2*a*).

HR-TEM confirmed that these structures mainly consisted of SWCNT bundles (Figure 2*b*) and also the absence of MWCNTs and amorphous carbon. Morphology was found to be similar to purified SWCNT bundles produced by laser ablation process. The average diameter of SWCNTs from TEM measurements was found to be 1.5 ± 0.1 nm.

A solution of ferrocene in *p*-xylene on sonication in the absence of silica powder did not produce SWCNTs. Therefore it is inferred that the presence of silica powder is essential for producing them. Fe nanoparticles produced during sonication can lead to catalytic growth of SWCNTs and also Fe particle growth by agglomeration. The authors opine that probably the very low concentration of ferrocene favours formation of SWCNTs¹².

Raman spectral studies of the CNTs, obtained by the sonochemical path, exhibited characteristics of a typical SWCNT – a strong G band (tangential mode) at 1572 cm^{-1} and a sharp radial breathing mode (RBM) in the lower wave-number region ($100\text{--}300\text{ cm}^{-1}$), with maximum intensity at 164 cm^{-1} . Analysis of the RBM

band gives SWCNT diameters of 1.1–2.1 nm, with an average diameter of 1.55 nm. The diameters of most SWCNTs (>90%) were in the region of 1.3–1.8 nm, and these values agree with that estimated from HR-TEM.

It is too early to account for SWCNT growth mechanism, but it is believed that the sonochemical treatment facilitates decomposition of ferrocene and *p*-xylene, offering the necessary temperature to synthesize SWCNTs.

The report by Jeong *et al.*¹² thus offers a simple method for producing high-purity SWCNTs under ambient conditions. The earlier reported methods require severe conditions such as high temperature, high vacuum or high voltage and some special equipment.

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