METHODS OF HTS DEPOSITION: THERMAL EVAPORATION

Werner Prusseit

THEVA Dünnschichttechnik GmbH
Hauptstr. 1b
85386 Eching-Dietersheim
Germany

INTRODUCTION

Among physical vapor deposition techniques thermal evaporation (TE) is the one with the longest standing tradition. However, during the last 30 years of booming semiconductor industry which involves a great deal of thin film technology, deposition techniques like CVD (chemical vapor deposition) or sputtering which often offer unquestionable advantages have been developed to perfection and TE has largely been replaced in production lines. On the laboratory scale, due to their simplicity, techniques like PLD (pulsed laser deposition) or sputtering were much more promising to realize fast results.

Consequently, when the new superconductors emerged only a handful of research groups like Berberich (1988), Terashima (1988), Kwo (1989), Prakash (1990), and Chew (1990) performed deposition trials based on TE. However, as time went by it became clear that the performance of the various deposition methods strongly depends on material issues as well as economic aspects. With progressive commercialization, cost effective volume production and reproducibility became the driving forces and the intrinsic advantages of TE turned the scales. In this sense, the story of high temperature superconductor (HTS) film deposition can serve as an example how this technique, sometimes regarded as old – fashioned, still bears a high potential for innovation and surprising efficiency.

In the following chapter we will review the basic features of TE when applied for HTS deposition in detail. The specific advantages and problems will be discussed in view of metal tape coating to estimate whether this technique provides a long term perspective for the fabrication of coated conductors.

GENERAL FEATURES OF THERMAL EVAPORATION FOR HTS DEPOSITION

TE is the classical technique applied for metal - plating of glass or plastic surfaces, like e.g. aluminium coatings widely used for capacitors, plastic wrappings, and as barrier against water diffusion. It is evident that the deposition of quaternary metal - oxide compounds imposes quite different requirements to the technique and will go far beyond the rudimentary concept of evaporating a single metal in a vacuum chamber.

The necessary features of a conventional HTS deposition system are depicted in figure 1. The metal species the superconductor is composed of are evaporated in high vacuum ambient. Usually, the chamber is pumped to 10^{-6} mbar background pressure. During deposition, the distance between the sources and the substrate which is in the range of several ten centimeters sets the scale for the required mean free path. Ballistic propagation of the vapor requires a residual gas background below 10^{-4} mbar, even when an oxygen flow is introduced.
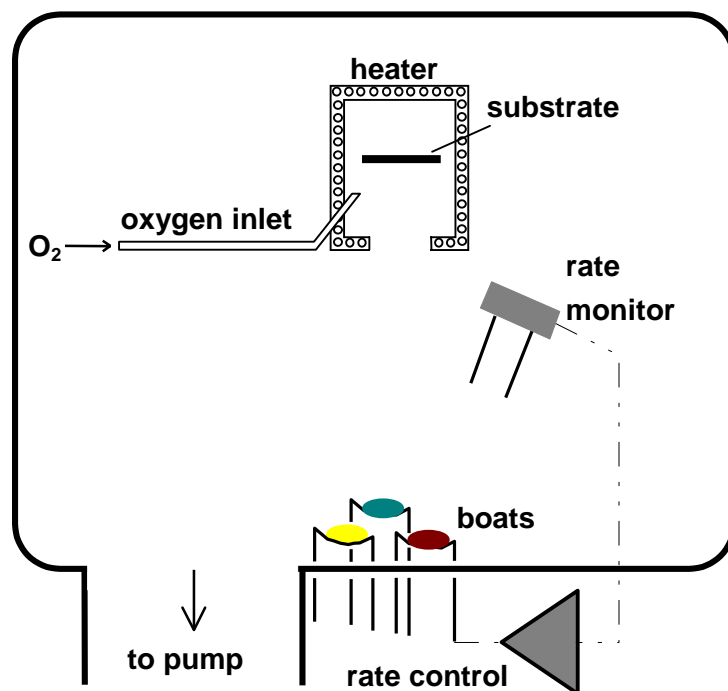
Figure 1. Main features of a conventional HTS evaporation system

To control the film composition the evaporation rates have to be online monitored individually by some kind of sensor heads. Feedback loops to the sources serve to stabilize the evaporation rates.

The substrate is mounted in or on a heater element and kept at a temperature which promotes epitaxial film growth. Since HTS require elevated oxygen pressure for their formation the introduction of oxygen is an essential but tricky task. To avoid flooding of the chamber with oxygen the main chamber is permanently pumped at, while the reactive gas has to be introduced close to the substrate. In the early days, a housing as described by Baudenbacher (1990) served to confine the gas around the substrate. Its small opening towards the sources constitutes an enhanced gas flow resistance and allows differential pumping to a certain extent.

Since the height of the region with enhanced oxygen pressure is comparable to its lateral extension, i.e. the dimensions of the substrate, this concept can be applied only for small chips (typically in the order of 10 – 20 mm). Otherwise, with increasing thickness of this oxygen zone the metal vapors start scattering. Since the scattering cross section depends on the molecular weight, as a first consequence the composition gets extremely pressure dependent. If the gas pressure or the length of the path through the oxygen is further increased, the vapor does not penetrate this barrier and cannot reach the substrate any more.

PROS AND CONS OF THERMAL EVAPORATION

System requirements

In comparison to most other techniques (PLD, CVD, sputtering) operating at forepump pressure level TE requires a high vacuum ambient and -- if a reactive gas flow is introduced -- also high pumping speed. These requirements can be met by oil diffusion -, cryo – or turbo molecular pumps. Since performance and reliability has been largely

improved in the last decade, turbo pumps are by far the most convenient solution especially if chambers have to be opened for substrate changing or if the process requires a backfilling with oxygen as in the case of HTS films. Since turbo pumps can be operated comfortably in a stop and go mode the higher investment costs pay because large gate valves necessary to disconnect continuously working pumps from the deposition chamber are not required.

On the other hand the vacuum specifications are mostly relaxed in comparison with semiconductor deposition processes which often take place under UHV conditions. Due to the low carrier densities in semiconductors even tiny impurity levels have significant if not detrimental effects on the electrical properties. In this respect, handling HTS deposition systems is a lot easier and there are only few precautions to avoid contamination when the system is opened or serviced.

Evaporation sources

For industrial scale deposition Knudsen cells (K-cells) and electron guns (e-guns) are the most common evaporation sources. Both types can hold a rather large volume of deposition material which usually renders them a good choice for long term deposition. However, with respect to reactive co-evaporation of HTS films there are also severe limitations.

Due to the reactive gas flow into the chamber in the long run metal-oxide skins build up on the surface in K-cells. Since the deposition rate is mainly controlled by the temperature of the cell the oxide formation reduces the vapor flow rate – in the extreme case to zero if the skin cannot be penetrated any more. As a consequence, even K-cells will require an online rate monitoring system which has to be very sensitive, since typical deposition rates of K-cells are an order of magnitude lower than those of e.g. boat sources and e-guns. To make things even worse the oxide growth of yttrium and other rare earths elements is not a self limiting process but the oxide thickens until the K- cell eventually fails. For this reason K-cells have been mainly used e.g. by Bozovic (1990) and Eckstein (1989, 1992) in MBE – type deposition systems with extremely low background pressure in connection with activated oxygen confined at the substrate location. Beyond that, large capacity K-cells are bulky which limits the uniformity of the film composition across a given area.

Some of these complications can be overcome by e-guns as used e.g. by Naito (1991) or Chew (1990). However, due to their short time constants they also put higher requirements to the speed of the rate control. Multi-component film material cannot be evaporated from a single source since most compounds are cracked by the e-beam and will not evaporate stoichiometrically. As a consequence, co-evaporation requires several independent sources. However, large e-guns are very bulky and cannot be positioned as close to each other as would be desirable for realizing a quasi – point source. Only a large source to substrate distance can compensate for this disadvantage, which in turn reduces the material efficiency. In this respect, e-guns and K-cells encounter the same problem. There are quite compact multi-liner e-guns available, but for the sake of space the liner capacity is very limited and the original advantage of the large material volume gets lost again.

Among the possible evaporation sources metal "boats" are the simplest but have yet turned out as very effective. Positive and negative aspects are summarized in table 1 and shall be discussed in more detail.

Boat sources are very compact and can be placed quite close to each other to approach the multiple species point source ideal which guarantees homogeneous film composition. The reverse of this medal is the limited capacity of such boats and in standard configurations the maximum YBCO film thickness achievable with one filling lies between 500 and 1000 nm. In view of long term operation, in situ refilling of such sources is a must.

Fortunately, even quantitative refilling from reservoirs can be accomplished by such means as e.g. vibrator conveyors. As the main advantage of this splitting into reservoir and evaporation source these large reservoirs can be placed independently at convenient locations and don't impede the boats.

Table1. The advantages and disadvantages of boat sources

Pros	Cons
compact	limited capacity
easy switching between many elements	not all elements available for evaporation
material cheap	
high rates available	
fine tuning of composition	rate control necessary

Typically, evaporation employs pure metals which are available in various forms like grains, turnings or even powder. They are usually stable and quite cheap compared to sputter targets or their complex metal-organic counterparts used for CVD.

Boat sources provide a rather high degree of flexibility. Deposition rates can range from a few Å/s to quantitative flash evaporation. The film composition can be tuned over a wide range to optimize the desired properties. In turn, the multi-source deposition requires a very accurate and stable control of the deposition rates as described below.

As a disadvantage the maximum temperature of the boat sources is limited by the boat material itself, usually, tungsten, tantalum or molybdenum. Consequently, elements with very high melting points or low vapor pressure are not available for TE. Nevertheless, most homologous 123-compounds are easily accessible replacing yttrium by other rare earth elements and without much changing the deposition parameters.

Composition control

No matter which sources are employed co-evaporation requires a close, accurate, and stable rate control of each channel. To be even more specific, this means an in situ online rate control with a time constant appropriate for a feedback loop to the evaporation sources.

An analysis of the growing film can be performed by RHEED or EDX and a combination thereof, like demonstrated by Kamei (1992). However, due to the limited signal to noise ratio and the strong thickness dependence of the signal the EDX in situ analysis can be regarded as exotic and is not applicable as standard manufacturing tool. RHEED and LEED are not sensitive to the elementary composition but were used by Eckstein (1990, 1992) and Naito (1995) to monitor composition - dependent surface properties of the growing film on a fixed and well oriented substrate. However, this technique is restricted to some fine tuning and does not replace other monitoring. The use of moving or polycrystalline substrates and for high deposition rates is practically impossible.

For this reason, only the analysis of the vapor composition in front of the substrate offers a chance for a reliable online rate control.

Note: The evaporation rate is a product of the vapor density times propagation velocity. Since the vapor originates from a melt the density is governed by an Arrhenius law, i.e. it depends exponentially on the temperature of the source, whereas the mean velocity (Maxwell distribution) scales with the square root of the temperature. Consequently, the velocity of the atoms in the vapor can be regarded as practically constant and rate changes are essentially caused by changes of the vapor density.

Due to the emission characteristics of the boats and temperature dependent sticking coefficients on the substrate surface these methods cannot provide absolute values but have to be calibrated empirically. However, they allow a quite accurate relative control to keep the rates and film composition constant over the deposition time.

Sensing the composition of metal vapor inside a vacuum chamber can be performed by a quadrupole mass spectrometer which is able to select and analyze the metal species due to their different atomic masses. This technique has been established and used by Chang (1973) for alloys and by Chew (1990) and Baudenbacher (1990) for YBCO. Usually, the quadrupole system has to be pumped differentially to ensure a long collision free path between the quadrupole rods and to save the filament of the electron source. The vapor is ionized by an electron beam in a cross beam configuration. This rate control has been successfully employed mainly for low rate deposition. To compensate drift it has to be re-calibrated against quartz crystal monitors.

EIES (electron impact emission sensors) employ a quite similar ionizing arrangement by an electron beam but detect the characteristic light emission from the metal species. Described by Lu (1977) it has been used for HTS deposition by Naito (1991, 1995). As in the case of the quadrupole, the emission filament in connection with the background oxygen constitutes a handicap in view of long term tape deposition.

The common, commercially available rate monitoring is based on frequency shifts of oscillating quartz plates due to the deposited material. These quartz crystal monitors are quite robust and easy to handle. Even for rates of a few Å/s the accuracy is in the range of a few percent and stability as well as reproducibility is excellent. Their only shortcoming becomes evident when used for long term processes like tape coating. When a certain material thickness has been deposited onto the quartz, the frequency shift is so large that the quartz fails oscillating. Multiple, exchangeable quartz heads may relax but not solve this problem.

For this reason, in recent years atomic absorption spectroscopy (AAS) has become an increasingly interesting alternative to monitor the vapor composition. It has been established by Klausmeier (1992), Shinohara (1991), and Lu (1995) for HTS film deposition. The basic operating principle as depicted in figure 2 is intriguingly simple. Light of a spectral line of the element to be analyzed is generated outside the chamber e.g. by a hollow cathode lamp or a laser, passes through the chamber and is detected by a photomultiplier on the other side. The light beam can be coupled into the chamber by lenses and apertures or optical fibers.
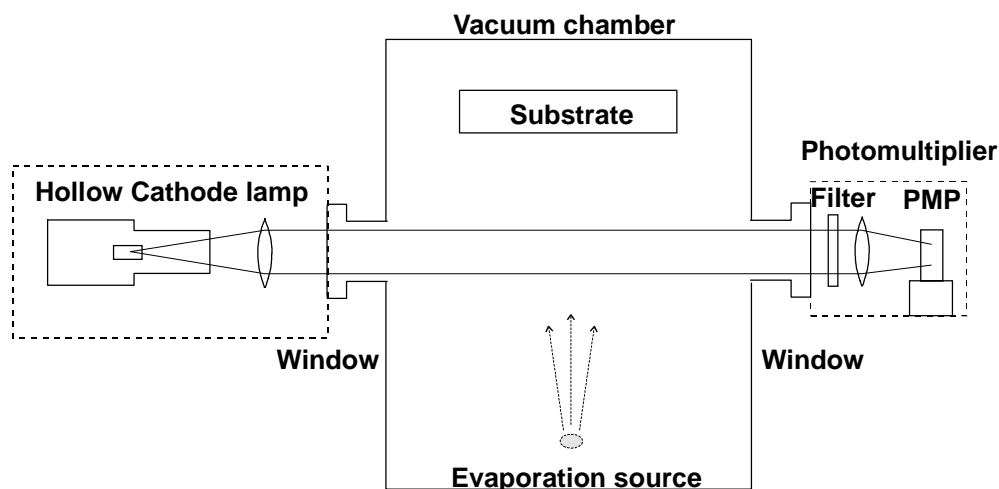

Figure 2. Setup of rate control by atomic absorption spectroscopy (AAS)

The weakening of this light by resonant absorption in the metal vapor is a direct measure of the vapor density and hence the deposition rate. The technique offers the advantages that all components can be placed outside the vacuum chamber, have long lifetime and allow easy access.

In spite of the apparent simplicity, however, the problems arising with AAS are manifold and it took quite a lot of additional technical efforts to guarantee the required long term stability. Some setups described by Lu (1995), Klausmeier (1992) and Utz (1996) use special precautions and reference beams to compensate for long term drifts of the light sources and detectors. To name only a few, difficulties can also arise from the absorption probabilities and wavelength of the transition, which can range from IR to UV. Tunable semiconductor laser sources have to emit a single mode, intensity stabilized beam of light. To reach frequencies in the UV or blue part of the spectrum, their output frequency has to be doubled or even tripled accompanied by a loss of orders of magnitude of intensity.

On the other hand hollow cathode lamps emit spectral lines broadened by collisions in the gas filling and are susceptible to aging effects. Beyond that, at higher deposition rates saturation effects in the absorption of the spectral lines by the vapor can render AAS control difficult.

In summary, the composition control which is an essential ingredient of TE systems can be handled today, and what seemed to be a disadvantage in the early days of coevaporation has turned into more flexibility for the optimization of composition dependent film properties. The best choice of the monitoring method, however, depends to a great extent on process requirements like deposition time and - rates.

Distance between sources and substrate

TE is a non-directional deposition method. The source to substrate distance can be chosen very large and automatically results in a high uniformity of the deposited films. This inherent uniformity is certainly one of the essential and unquestionable advantages of TE over other methods. Due to the fact that a large area can be coated simultaneously a second important consequence is the high volume deposition rate.

The emission characteristics of the boats can be calculated directly and the larger the source to substrate distance the better is the resulting uniformity of the film thickness, composition, and the physical properties. This is in direct contrast to all short range plasma techniques (PLD, sputtering) where inhomogeneities of the plasma or target are directly mapped onto the substrate.

Obviously, there is a trade off between uniformity and material exploitation which inevitably drops quadratically with increasing distance. To achieve acceptable homogeneity for fixed substrates and a deposition area of about 400 cm^2 the material efficiency is in the order of about 5%. For a tape coating arrangement it seems feasible to increase this efficiency up to 15%.

The fact that a lot of material is deposited all over the chamber bears another problem of massive contamination and flaking, since during long term operation quantities in the order of kilograms are vaporized. All components directly exposed to the vapor will be coated and since the material is hygroscopic flakes start to peel off when the system is opened giving rise to dust problems. Capturing material which propagates in wrong directions and thus confining the vapor in a "deposition chimney" can be realized by metal screens.

Substrate heater and oxygen supply

The most critical component of the deposition system is the substrate holder. Epitaxial growth of HTS films requires high substrate temperature as well as reactive gas ambient. Consequently, the substrate holder comprises both heating elements to obtain a

homogeneous temperature distribution across the entire substrate area and a reactive gas supply unit.

Optimum temperature uniformity is realized by black body radiation from heated walls surrounding the sample. Backside heater plates which are often used for plasma techniques to allow access to the substrate surface suffer from changes in the IR transparency of the substrate during film growth and also depend strongly on the substrate material. The arrangement which comes closest to the ideal consists of a furnace with a small opening to allow access of the vapor as already depicted in figure 1. Such a small opening can also serve as a flow resistance for the reactive gas introduced in the neighborhood of the substrate, cf. Baudenbacher (1990).

However, due to the small opening and the argumentation above this simple concept is only applicable for small substrates and the main advantage of TE gets lost. Two ways to resolve this dilemma have been pursued successfully:

a) The use of highly reactive gas at such low pressure that the vapor propagation is not impeded. For HTS films ozone and atomic oxygen activated by downstream plasma sources or in a discharge, and even directional oxygen beams from RF sources have been employed by e.g. Terashima (1988), Kwo (1989), Prakash (1989, 1990), Chew (1990), Eckstein (1989), Utz (1995) and Sato (1997). However, the activated gas supply bears a lot of technical problems, like the low degree of activation, recombination at walls before the substrate is reached, and inhomogeneous distribution across large areas. Using e.g. an ozone distillery to enrich the gas may work on a laboratory scale but due to the high danger of explosions it is not a safe solution for industrial scale production. Besides, even when using activated oxygen for large area deposition the gas flow into the chamber is still very high and requires enormous pumping speed to maintain an acceptable background pressure.

For the deposition of bismuth - based superconductors, however, it has turned out that only activated gas as employed by Eckstein (1990) and Utz (1995) can supply the necessary oxidation potential and is the only practicable way to grow BSCCO - or BKBO – films by TE.

b) Molecular oxygen at high pressure can be used when confined in a tricky way around the substrate. In this respect, the breakthrough was obtained by Berberich (1993, 1994). The discussion of the basic idea and the design of this heater shall be saved for the next section. It should just be noted here that it enables deposition on very large wafers of more than 8 inches in diameter and has become a real production tool for fabrication of the greater part of the large YBCO films worldwide.

This section should not be concluded without noting that deposition by TE employs the lowest substrate temperatures of all deposition techniques, typically around 670 – 690°C compared to 750 – 850°C for other techniques. It could be demonstrated by Baudenbacher (1997) that the YBCO lattice is formed even at temperatures as low as 490°C. The lower substrate temperature may turn out as a crucial point in view of tape coating since diffusion and unwanted substrate reactions are temperature activated processes which are slowed down if not halted at lower temperature. The probable reason for the lower film growth temperature lies in the higher surface mobility of metal atoms compared to metal oxide molecules which are already present in the gas phase for those deposition techniques involving hot plasma conditions.

LARGE AREA, LONG TERM DEPOSITION

Spatial separation of deposition and oxidation

To a great extent large area YBCO – films are produced by vacuum evaporation employing molecular oxygen in an arrangement first developed at the Technical University of Munich in 1992 by Berberich (1993, 1994). The basic idea goes back to a RHEED – film growth study. In this survey, the intensity variations of the specular reflected e-beam were analyzed as a function of deposition time. Layer by layer growth gives rise to well known RHEED oscillations as a consequence of modulations of the surface roughness, first observed by Terashima (1990). Since the overall disorder inevitably increases with deposited film thickness these oscillations are damped. When closing a shutter in front of the substrate to stop deposition, however, the signal intensity recovers to a certain extent. It can be interpreted that the YBCO surface is still under construction even after metal atoms have stopped to impinge upon the substrate. From such measurements Baudenbacher (1997) could determine a time constant in the range of a second until the metal atoms are getting to rest at their final positions in the YBCO lattice. If metals are moving around for about a second until they are eaten up by chemical reactions (oxidation) they will not experience any difference if oxygen is supplied a few tenths of a second after they had reached the substrate surface. Consequently, the substrate can be shifted between a high vacuum metal deposition zone and a high pressure reaction zone as sketched in figure 3.
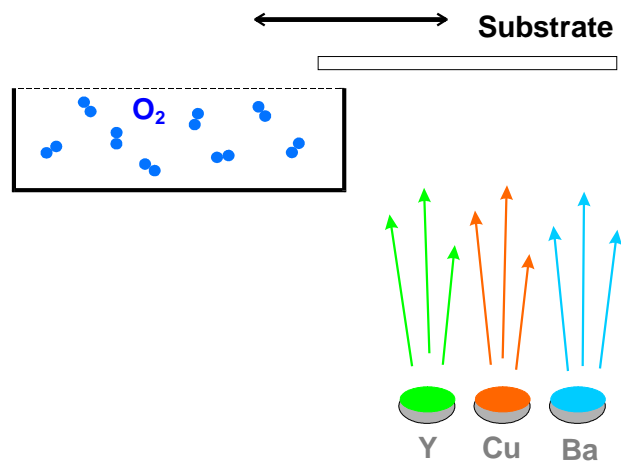

Figure 3. Basic principle of the oxidation pocket

As a main advantage of this arrangement the oxidation conditions can be chosen more or less independently from the vapor deposition conditions and a much wider pressure range becomes accessible.

Turntable substrate holder for wafer deposition

Since it is hardly possible to move the substrate from one chamber to another on such a short time scale the substrate itself has to be a part of the chamber. Placing the substrate quasi as a lid with a narrow spacing on top of the oxygen pocket the slit around the edge constitutes a high gas flow resistance. The efficiency of such a "slit seal" improves quadratically with decreasing slit width.
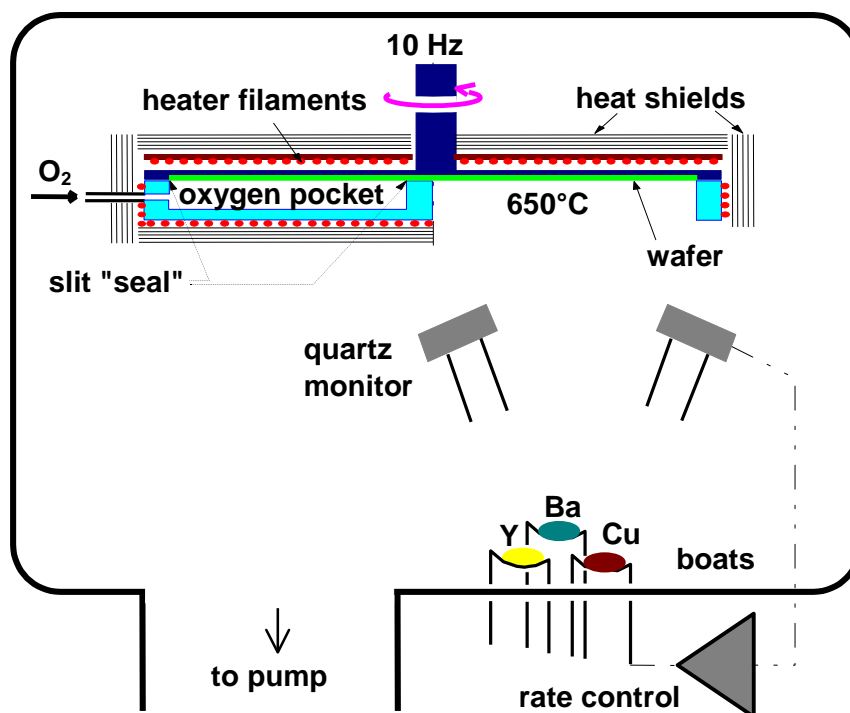
Figure 4. Operating principle of the turntable substrate holder

The practical solution has been realized in the form of a turntable substrate holder as depicted in figure 4. The substrate is mounted on a plate spinning with a frequency of 5-10 cycles per second. The oxygen pocket is placed closely underneath the substrate and covers a sector of the total area while metal vapors from the sources below have access to the substrate in the open area. By a proper mechanical arrangement the slit width can be maintained between 0.3 and 0.5 mm across a deposition area of 9 inches in diameter, resulting in a pressure drop of three orders of magnitude between the oxygen pocket and the vacuum chamber, cf. Utz (1997a). Consequently, the metals deposited in 10^{-5} mbar background pressure are oxidized in 10^{-2} mbar pure oxygen which suffices to build up the YBCO crystal lattice. Except for the deposition opening the substrate is surrounded by heater filaments and heat shields, which is a quite close approach of the ideal furnace geometry described above.

Present day deposition rates are typically in the range of 20 - 30 nm/min. However, no efforts have been made yet to speed up the process further.

The oxygen shuttle concept

Although this turntable concept has been proven successful and became the standard technique for film production on single crystal wafers the movement restricts its use to substrates of a certain size. Especially, when thinking of very large rectangular plates or metal tape substrates it becomes immediately clear that they won't allow a spinning motion.

For this reason the principle has been inverted by Kinder (1996). Changing the frame of reference leaves the substrate fixed and moves the oxygen pocket instead. Again, the slit seal around the oxygen pocket allows a homogeneous high pressure oxygen shower covering the entire deposition area several times each second. A schematic view is depicted in figure 5 showing the oscillating oxygen shuttle beneath the substrate plate.
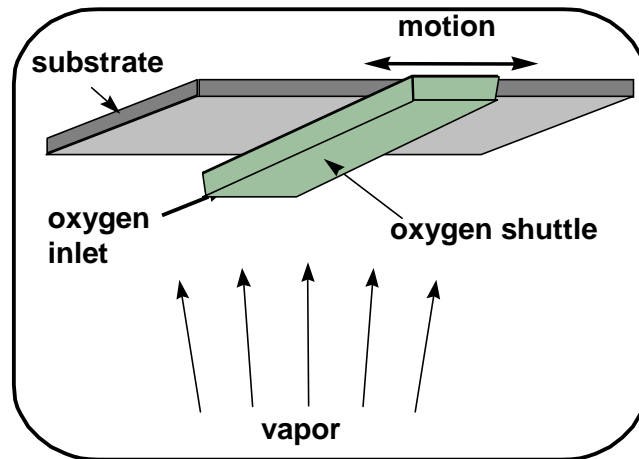
Figure 5. Oxygen shuttle arrangement

It should not be concealed that this kind of arrangement leads to distinct disadvantages compared to the turntable heater. One which is immediately evident is that it will result in a somewhat more open heater configuration deviating from the ideal closed geometry favored above. However, with respect to tape coating this problem is relaxed since the metal substrate is non-transparent and has a high thermal conductivity which improves the temperature uniformity.

In summary, the choice of the heater arrangement largely depends on the application and the involved substrate material. In most cases when wafers have to be coated the turntable heater is certainly the optimum solution. However, when aiming at long lengths tape coating there is no alternative to the oxygen shuttle. Fortunately, some of the disadvantages of this configuration are reduced when using metal substrates.

Long term continuous operation

In recent years several improvements have been achieved to allow a long term operation of the TE deposition.

Since the capacity of the boat sources is limited an in situ refilling scheme is an absolute necessity. A variety of solutions seem feasible in this respect. One of the most elegant ways which does not involve much mechanics inside the vacuum chamber are vibrator conveyors driven by electromagnets as introduced by Utz (1997b). They can be placed at convenient positions and are very reliable standard tools used in industrial processes for hauling granular material. Several TE systems have been successfully equipped with conveyors already.

Another essential item is the rate control. Since the quartz crystal monitors get exhausted, the AAS – based rate monitoring is the only practical alternative to control long term processes like tape coating. All components are situated outside the vacuum chamber, offer long lifetime and easy access for servicing. However, practical long - term tests of even some hours are still lacking.

TAPE COATING

Substrates

Since large angle grain boundaries are detrimental for the current carrying capacity YBCO films have to grow highly oriented on a macroscopic scale. There are various techniques to achieve a high degree of alignment in the YBCO films by texturing the underlying substrate and buffer layers. They are described in detail in specific chapters of other authors and should only be mentioned here with respect to evaporation.

A nickel or nickel alloy based metal substrate can be textured by mechanical deformation (RABiTS). The subsequent buffer and superconductor layers will then adapt to the long range order of the substrate crystal grains similar to epitaxial film growth on single crystals. By ion beam assisted deposition (IBAD) and inclined substrate deposition (ISD) a buffer layer which is deposited onto a polycrystalline or even amorphous substrate is aligned due to an impinging ion beam or due to the growth kinetics under oblique material deposition.

The RABiTS approach works best with metals like nickel and Ni - alloys. Since the sensible material is easily damaged, handling and the tape transport during film deposition is crucial. Beyond that, most metals form stable oxide surface layers which can prevent the film growth with the desired orientation. Consequently, the chemistry and thermodynamics under deposition conditions play an important role.

The IBAD technique is based on a selective growth of crystal grains with the desired orientation by interaction with an ion beam which is incident on the substrate during deposition. This process is usually very slow. Nonetheless, IBAD is the most advanced alignment technique and still yields the best results for the critical current density comparable to films grown on single crystals. As another advantage IBAD does not depend on the substrate material and can be applied even to stainless steel. Although TE has been demonstrated to yield high quality YBCO films on IBAD buffers by Bauer (1998), the deposition of the IBAD buffer layers itself has been performed by PLD or sputtering.

The ISD technique depends on the growth kinetics at very high deposition rates. PLD as well as evaporation are capable to achieve the required rates. Its great potential originates from the fact that ISD produces textured buffers in a very short time. Although the results still fall behind those achieved by IBAD, it is certainly the most economic process to grow textured buffer layers.

Deposition on short samples

We have used evaporation in connection with RABiTS as well as ISD to grow buffer layers and YBCO films on short metal tape substrates up to a length of 12 cm. Results obtained with both techniques are comparable and promising.

Following the ORNL route and adapting it to evaporation, we have deposited a 100 nm thick CeO_2 buffer layer on Ni alloy tape in a two step process, cf. Egly (2000). To reduce the native and randomly aligned nickel oxide on top of the substrate surface the tape is heated in forming gas atmosphere to the deposition temperature of 650° C followed by deposition of a 10nm thin CeO_2 layer in reducing ambient. The residual 90 nm of CeO_2 are deposited after pumping away the forming gas and switching to an oxygen gas flow. Due to the lower substrate temperature applied for thermal evaporation even this 100 nm thick CeO_2 buffer layer is sufficient to prevent interdiffusion. Consequently, this processing step is shorter and cheaper than the multiple buffer layer deposition usually used for PLD and other techniques requiring higher substrate temperatures. The alignment results for the Ni-substrate and YBCO film are depicted in figure 6.
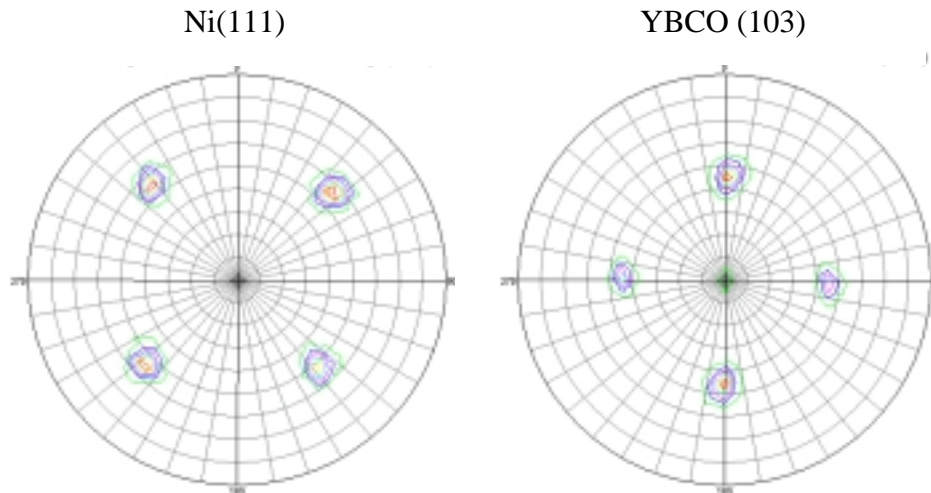
Ni(111)   YBCO (103)

Figure 6. XRD pole figures of Ni (111) and YBCO (103)

In the case of ISD buffer layers thermal evaporation employs MgO; cf. Bauer (1999); instead of YSZ which is used for PLD by Hasegawa (1998). The deposition of the textured buffer layer is performed at a rate of about 500 nm/min and takes only a few minutes. The details and peculiarities of this technique are described in a separate chapter of this book.

The subsequent YBCO film is deposited under standard conditions described above. In situ metallization with gold or silver can be applied to ensure a low resistivity contact to the superconductor.

Our deposition trials on ISD and RABiTS buffers resulted in an in-plane alignment of the YBCO films with a FWHM of the phi-scans or pole figures in the range of 7°-10° (cf. figure 6). 500 nm thick YBCO films on short samples (3-10 cm) exhibit transition temperatures between 86 – 87 K and critical current densities of 0.5 – 0.8 MA/cm^2 in zero field at 77K.

A common problem of ex situ YBCO annealing techniques, like the BaF$_2$ - or TFA – process, is the degradation of the superconducting properties of thicker films. By our in-situ process, we deposited YBCO - films up to 1.4 μm thickness by TE on 12 cm long tape samples. There was no indication of any degradation of the current carrying capacity and current values of 60 – 100 A in this 1 cm wide tape conductor translated into current densities of 0.5 – 0.7 MA/cm^2 .

YBCO deposition on long length tape

The short sample results obtained so far were achieved with the turntable heater. Although the substrate holder arrangement cannot be scaled to a length larger than about 20 cm, the processing steps and deposition conditions were developed to be compatible with continuous long length tape deposition. Consequently, the main task to be solved consists of demonstrating a proper configuration for long length tape deposition and an adequate tape transport mechanism.

Tape transport

It is rather straightforward to employ the oxygen shuttle arrangement for a tape coating apparatus. However, there are different ways to handle the tape transport through the deposition zone. Efficient tape coating should make use of the large area which can be covered simultaneously to achieve a high volume production rate. The first approach would imply the use of an about 20 cm wide metal foil covering the width of the area and a simple linear reel to reel transport. However, since the distance between oxygen shuttle and

substrate surface is very narrow and critical, the requirements on the flatness of the substrate are very tough. Internal stresses in the metal can easily result in warping when the metal is heated to the deposition temperature. For this reason, splitting the broad metal sheet into parallel, narrow tape tracks which can be guided at the edges appears to be the better solution.

However, even such an arrangement has its disadvantages. To name only a few, e.g. in a given span of time only relatively short tape pieces can be produced and variations in the temperature profile and the composition across the deposition area will result in different quality of the tape tracks.

To obtain longer tape and to average over process conditions it is advantageous to wind a single tape back and forth to cover the whole deposition area in multiple turns. The principle is sketched in figure 7. However, more work has to be done to make this scheme working.
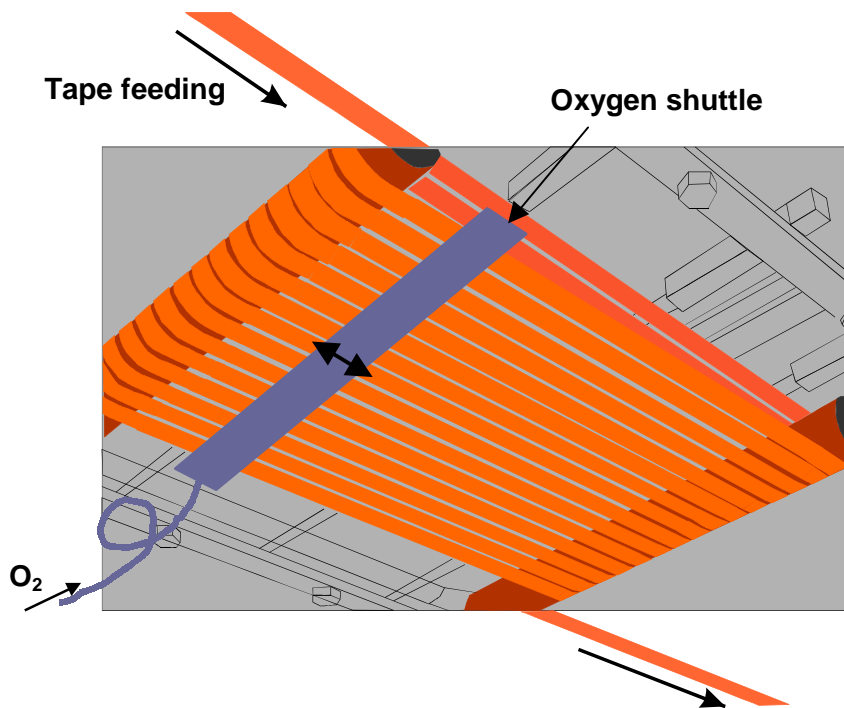

Figure 7. Multipass tape transportation in combination with oxygen shuttle

In summary, thermal evaporation has already been demonstrated to handle the whole tape deposition process from aligned buffer layers to thick YBCO films and in situ metal coatings on short samples. The extension to long length continuous deposition of several ten meters is currently under development. Cost calculations indicate that this technique may be a competitive solution. What remains to be done with respect to the mechanical arrangement is the demonstration of feasibility of longer lengths, in conjunction with reliability and long term stability. Yet, the most crucial remaining task is the enhancement of the critical current density to over 1 MA/cm^2 at 77K for the most economic deposition routes.

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